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STATION TO INSTRUMENTED AIRCRAFT L-BAND TELEMETRY SYSTEM AND RF SIGNAL CONTROLLER FOR SPACECRAFT SIMULATIONS AND STATION CALIBRATION

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AUGUST 1971

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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ABSTRACT

An L-band telemetry system designed to provide the capability of near-real-time processing of calibration data from the Goddard Space Flight Center network stations by a NASA instrumented aircraft (NASA 428) is described. The system also provides the capability of performing computerized spacecraft simulations, with the aircraft as a data source, and evaluating the network response. The salient characteristics of a telemetry analysis and simulation program (TASP), which is a current application of the system, are discussed together with the results of TASP testing.

The results of the L-band system testing have successfully demonstrated the capability of near-real-time processing of telemetry test data, the control of the ground-received signal to within ±0.5 dB, and the computer generation of test signals. This effort has established the framework for follow-on network testing programs such as near-real-time processing of Minitrack calibration data, collection and processing of PACT calibration data for control of the airplane, and acceptance testing of new antenna and receive systems.

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STATION TO INSTRUMENTED AIRCRAFT L-BAND TELEMETRY SYSTEM AND RF SIGNAL CONTROLLER FOR SPACECRAFT SIMULATIONS AND STATION CALIBRATION

by
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1. INTRODUCTION

This report describes an L-band telemetry system designed to provide the capability of near-real-time processing of calibration data from the Goddard Space Flight Center (GSFC) network stations by a NASA instrumented aircraft (NASA 428). The system also provides the capability of performing computerized spacecraft simulations, with the aircraft as a data source, and evaluating the network response. In addition, the salient characteristics of a telemetry analysis and simulation program (TASP), which is a current application of the system, are discussed together with the results of TASP testing.

2. HISTORY

An instrumented aircraft (DC-6) is used in the performance of calibrations and quality-control measurements of the network tracking, telemetry (data-acquisition), and command systems [i.e., Minitrack (M/T), range and range rate (RARR), 40- and 85-ft dishes, and satellite automatic tracking antenna]. Also, the instrumented aircraft is used for space-flight simulations or fly-bys in preparation for spacecraft missions supported by the network. Previously, in the performance of the stated aircraft missions, most test results could not be analyzed or evaluated until the raw data had been returned to GSFC for processing. The time loss involved under this procedure penalized both the post-test analysis of data for completeness and validity, and the timely implementation of corrective measures to the systems tested. Whenever post-test analysis revealed incomplete results, which might have occurred for a number of reasons, a field trip would have to be rescheduled, with a resultant cost in time and money.

To overcome this problem, the instrumented aircraft was implemented with airborne-qualified data-processing equipment [digital computer, real-time computer peripherals, digital input/output devices, analog-to-digital (A/D) converters, and so forth], which allowed processing and evaluation of the data while the aircraft was still at the network station. Although the major and important task of obtaining test results before the aircraft left the

station had been accomplished, there remained the costly operation of repeating fly-by tests if the original test did not yield the data desired. Furthermore, the aircraft could not always be scheduled while in the field for additional testing because of an advance network station testing schedule, inclement flying conditions, or delays in obtaining processed data (the distance between an airport and a station is typically 40 miles, and at one site is approximately 200 miles).

The addition of an L-band telemetry system provided the means for returning the test data to the aircraft during the course of the test. The flight test engineer can ascertain the status of a test from examination of displayed "quick-look" data and from processed data immediately following a test run, thus enabling him to restart or repeat the test during the fly-by mission. The system also allows the aircraft to function as a data source for simulations and, by means of a computer-controlled radiofrequency (RF) attenuator, can maintain desired signal levels at the ground receivers. Therefore, the L-band telemetry system, coupled with the aircraft data generation and processing facility and RF signal controller, provides the capability for in-flight, near-real-time data analysis and post-test evaluations of spacecraft simulations and calibrations. This provides the capability for extensive field station testing and the timely implementation of corrective measures to the systems tested.

3. SYSTEM DESCRIPTION

The basic block diagram of the L-band telemetry system is shown in Figure 1. The required calibration data for analysis by the airborne computer from both the station equipment (e.g., Minitrack data) and special test equipment [e.g., portable aircraft calibration tracker (PACT)] are fed into the commutator for time multiplexing and formatting into the uplink data stream. After transmission to the aircraft through the RF link, the 300-kbs data stream is signal conditioned and decommutated. The decommutator performs frame synchronization and serial-to-parallel conversion, presenting 16 parallel lines as input to the airborne computer for data analysis and display by a high-speed printer and plotter or for storage on magnetic tape.

A current unique application of this system is TASP. Here, the computer is used as a data generator to produce pseudorandom (PR) data to be transmitted to the ground station under test via a 136-MHz, 400-MHz, 1700-MHz, or S-band airborne transmitter. The PR data are passed through the network receive system and looped back through the L-band telemeter to the airborne computer for error comparison with the original PR data. If the L-band telemeter has introduced no errors or perturbations, the performance of the network receive system can be determined. To evaluate the network receive system at various signal levels and to have the capability of controlling that signal level as accurately as possible, an RF signal controller was added to the system. The signal controller is basically a wideband computer-controlled RF attenuator that changes the effective radiated RF power from the NASA-428 downlink transmitter to maintain a desired signal strength at the network ground station. During a typical simulation flight, the RF signal controller can effect changes by as much as 70 dB to maintain the desired signal level at the ground. This change in received power is primarily due to relative range and orientation changes between the aircraft and the network

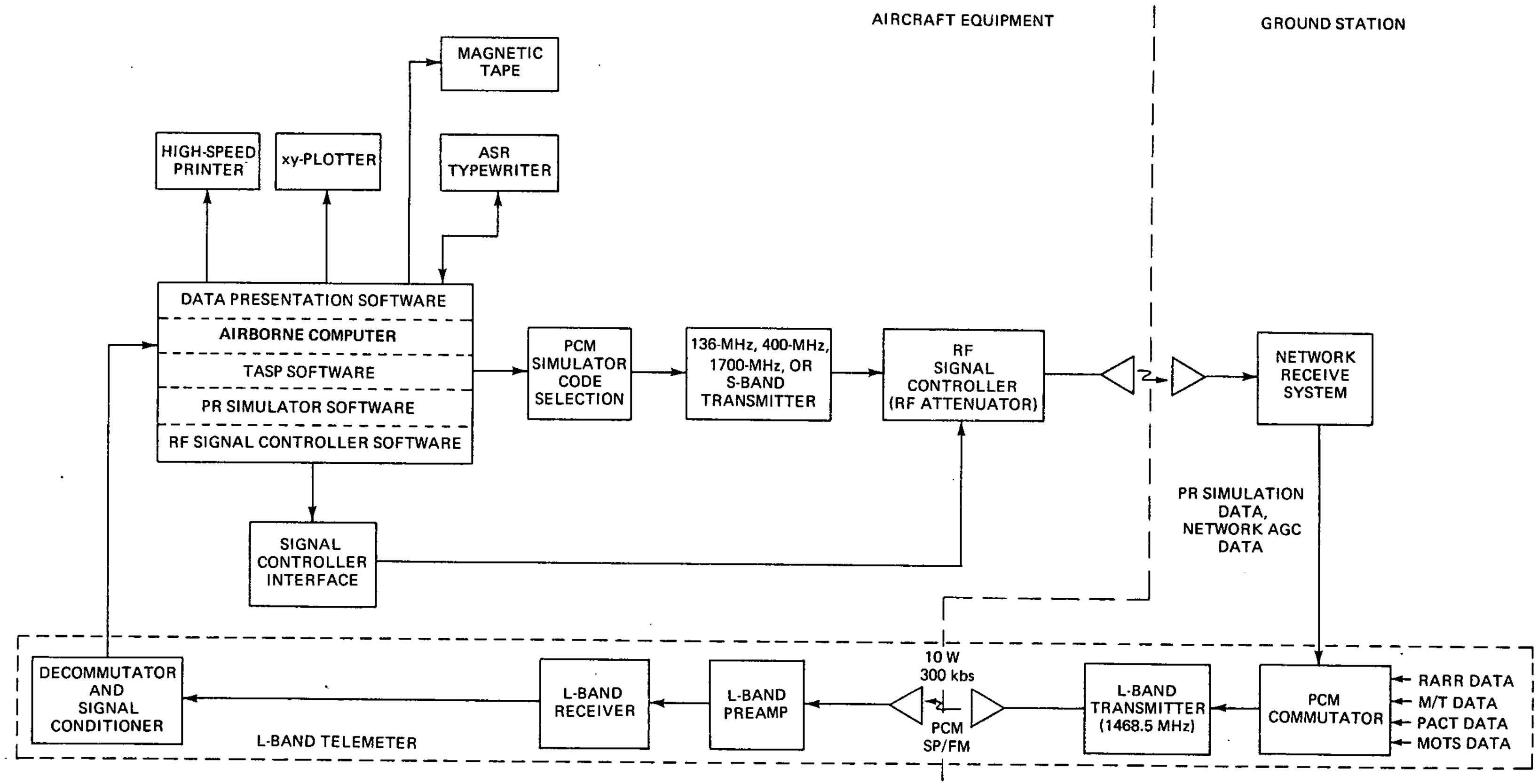


Figure 1—L-band telemetry system.

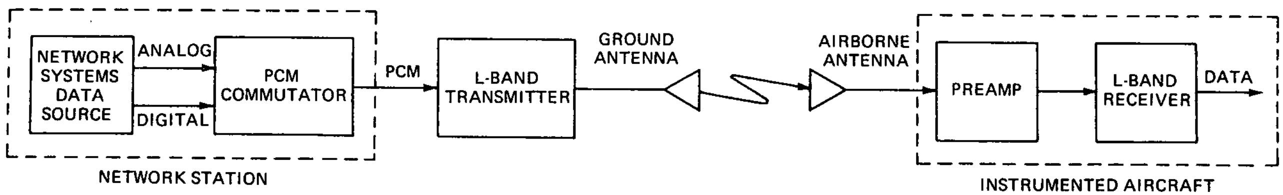


Figure 2—L-band telemeter.

station. The control signal for the RF signal controller is obtained by having the computer continuously compare the current ground automatic gain control (AGC) value with the precalibrated AGC curve for the station under test.

The above discussion very briefly defines the signal flow through the L-band telemetry system and describes a single unique application. Subsequent sections describe the system in further detail.

L-Band Telemeter

The L-band telemeter, shown in Figure 2, was designed to accommodate the large number and various types of data required to be transmitted from the ground station to the overhead aircraft. Of primary importance was the requirement to supply essentially error-free data to the airborne data processing equipment for a variety of flight patterns (e.g., circular orbits, zenith passes, and procedure turns). Also, convenient portability had to be considered.

The basic channel frequency and RF power for the telemeter were selected on the basis of noninterference with other L-band users. As is shown in Appendix A, the link signal margin analysis indicates sufficient signal strength to ensure essentially error-free uplink data transmission. The basic modulation scheme is pulse code modulation (PCM)/split phase/frequency modulation (FM). PCM was selected to handle the analog and digital signals, which required various sampling rates. Split phase was chosen as the coding technique to provide sufficient binary transitions for the airborne bit synchronizer. This was necessary since the clock must be extracted from the PCM data train, as opposed to a coherent system, which has a separate clock. The tradeoff between the higher bandwidth necessary for a PCM split-phase signal and the airborne bit synchronizer performance is justifiable in terms of the available link circuit margin.

The decision to use FM as the modulation scheme was based upon the premise that, first, the link would always be operating above the FM threshold point, thereby having the advantage of the FM modulation improvement factor; and second, the availability of airborne FM receivers and transmitters would be greater than for either phase modulation or amplitude modulation (AM) at a reasonable cost and delivery schedule.

The FM modulation index is limited to a maximum of approximately 2 by the maximum deviation capability (±500 kHz) of the L-band transmitter. From Appendix B, the total number of significant sidebands at a modulation index of 2 for square-wave modulation is 6. At this modulation index, the carrier power drops to zero, which means all power is in the modulation sidebands—an efficient modulation scheme. The critical bandwidth in the system is the second intermediate-frequency (IF) receiver bandwidth, which precedes the FM discriminator; it is set at 2.2 MHz. The following budget analysis verifies that 2.2 MHz is satisfactory:

Doppler shift	(negligible)
L-band transmitter instability	15 kHz
L-band receiver instability	75 kHz
Modulation bandwidth	1800 kHz
Total	1890 kHz

In the worst case, this allows a 0.31-MHz margin, which is adequate to minimize distortion and handle severe frequency shifts.

Since the relative orientation between the ground and airborne L-band antennas changes during a flight, each antenna is designed to provide near-hemispherical coverage with an average gain of approximately 3 dB above a circularly polarized isotropic radiator. Both polarizations are circular (left hand) to preclude polarization reversal and consequent loss of signal.

To achieve good receiving sensitivity in the airborne portion of the L-band telemeter, a preamplifier with a noise figure of 3.5 dB and a gain of 25 dB is used. The improvement in sensitivity with the preamplifier is approximately 6.3 dB over that achieved when the receiver is used as the front-end device.

At the ground transmitting end of the telemeter link, the L-band transmitter and its associated power supply are housed in a lightweight fiberglass suitcase that is easily portable (see Figure 3). The antenna and aluminum ground plane are attached to the inside surface of the suitcase; in effect, the suitcase acts as a radome for the antenna.

The transmitter is mounted on an aluminum plate to aid in dissipating the 100 W of excess dc power. For additional cooling, two fans in a push-pull arrangement keep air circulating throughout the suitcase. In setting up the suitcase, the top half containing the equipment is disconnected from the lower half, and by means of telescopic legs, it is positioned for operation in an unobstructed RF area. The ac power and modulation input are provided externally from one of the station buildings. The PCM commutator is located inside the field-station building and strategically positioned to accept the analog and digital signals from the systems under test.

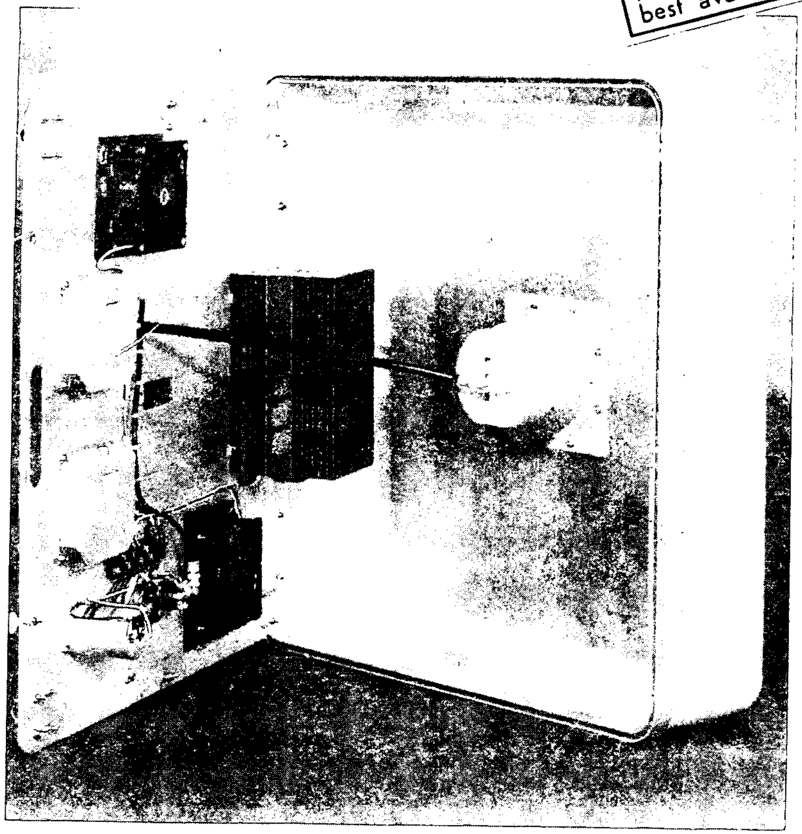
At the airborne end of the link, the L-band antenna is flush mounted on the underside of the aircraft, with the aircraft skin serving as a ground plane. The preamplifier is shock mounted adjacent to the antenna to minimize cable loss and system noise figures. The airborne receiver is designed to perform satisfactorily in the aircraft environment (see Appendix C for environmental requirements).

RF Signal Controller

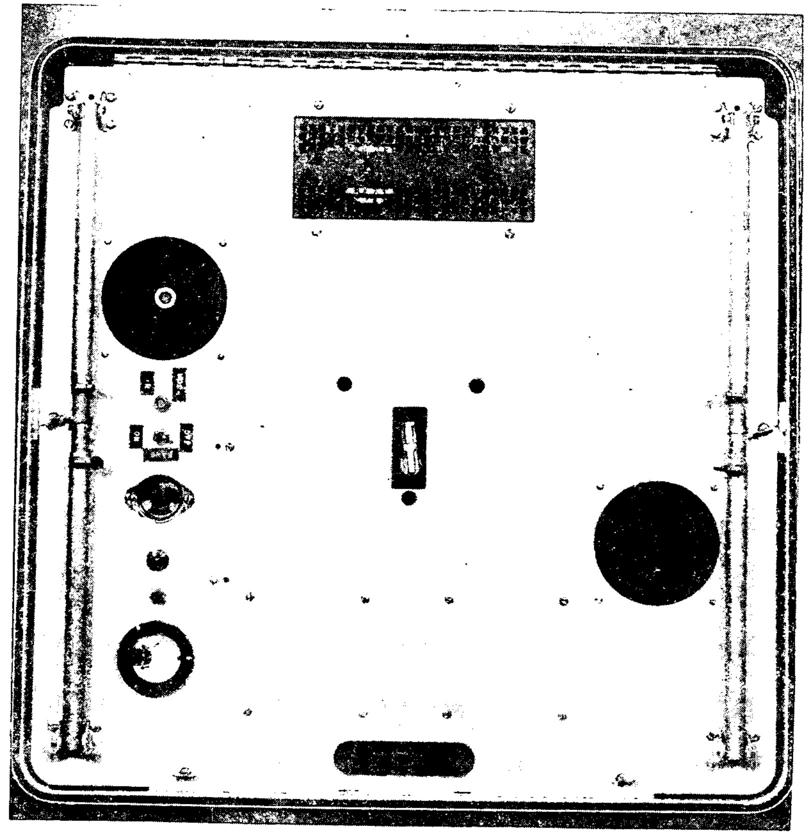
A valid appraisal of the performance of the ground system under test requires that the received signal is constant or varying in a predetermined manner. However, when aircraft simulations are being conducted, the signal strength at the ground station varies, and it is the task of the RF signal controller (the PIN-diode* attenuators) to keep the signal strength constant.

During the TASP test, the calibration aircraft flies in a circular pattern over the network station while it transmits the generated PR data. Because of the aircraft's flight dynamics (e.g., rolling), the nonsymmetrical pattern of its downlink antenna is continually changing its orientation with respect to the receiving station's antenna as the plane makes a test run. This orientation of the antenna patterns causes the resultant gain of the antennas to

*PN-junction diode.



(a)



(b)

Figure 3—L-band transmitter and antenna system housed in fiberglass portable suitcase: (a) inside view of top half; (b) top half with telescoping legs.

to fluctuate. The fluctuation in gain appears at the receiver as a variation in signal strength.

An AGC signal is developed from the incoming signal at the station receivers. This signal is sent to the commutator, where it is A/D converted, and then transmitted by means of the L-band uplink to the airborne computer, where it is compared to a desired AGC level. The computer then generates an error signal by means of the AGC monitor and update software section of TASP. The error signal is used to adjust the PIN-diode attenuators, which are located between the airborne telemetry transmitters and antenna, thereby compensating for the changes in signal strength at the receiving station. The PIN-diode attenuator used has a linearity of better than 1.0 dB, a switching speed of less than 1.0 μs, and a dynamic range of 35 dB.

The linearity was an important consideration in simplifying the programming of the computer. If the attenuator has a linear attenuation vs. control voltage response, the error signals obtained from the ground system need only to be multiplied by a constant to obtain the required correction voltages. However, if the curve is not linear, the entire response curve must be stored in the computer memory in the form of a table. As can be seen in Figure 4, the response of the PIN-diode attenuator is linear from 4 to 35 dB of attenuation. It was found necessary to bias the attenuator so that no attenuation less than 4 dB was obtained.

The switching speed of less than 1.0 μs is adequate since the AGC response time of the telemetry receivers used in the network can vary from 3 to 300 ms only. The dynamic range of the attenuator is 35 dB. This was not sufficient, since test results showed that the received signal level from the calibration aircraft varied by as much as 50 dB. Therefore, it was necessary to use two attenuators connected in series.

TASP

Four major tasks are performed by TASP. There are several facets of each major task, and they will be discussed in detail in the TASP software module section. The general program requirements for the major tasks are (1) to generate a PR data train, (2) to maintain a constant power level at the input of the ground system under test, (3) to store the received PR data train, which was retransmitted to the aircraft's data processing facility, and (4) to determine the status of the test from the stored data and perform statistical processing of the data.

The original concept of the data generation software was to provide a variable PCM telemetry format that would allow operator selection of such parameters as bit patterns, special word locations, and word, subframe, and frame lengths. This capability would permit spacecraft PCM data formats to be readily programmed and used for conducting network simulations. Although this software program could not be developed in the operational time frame for the telemetry system, it will be considered for future project-oriented simulations.

The computer generation and analysis of a PR data test signal is compatible with an existing aircraft PR hardware test system which was advantageously used for the software

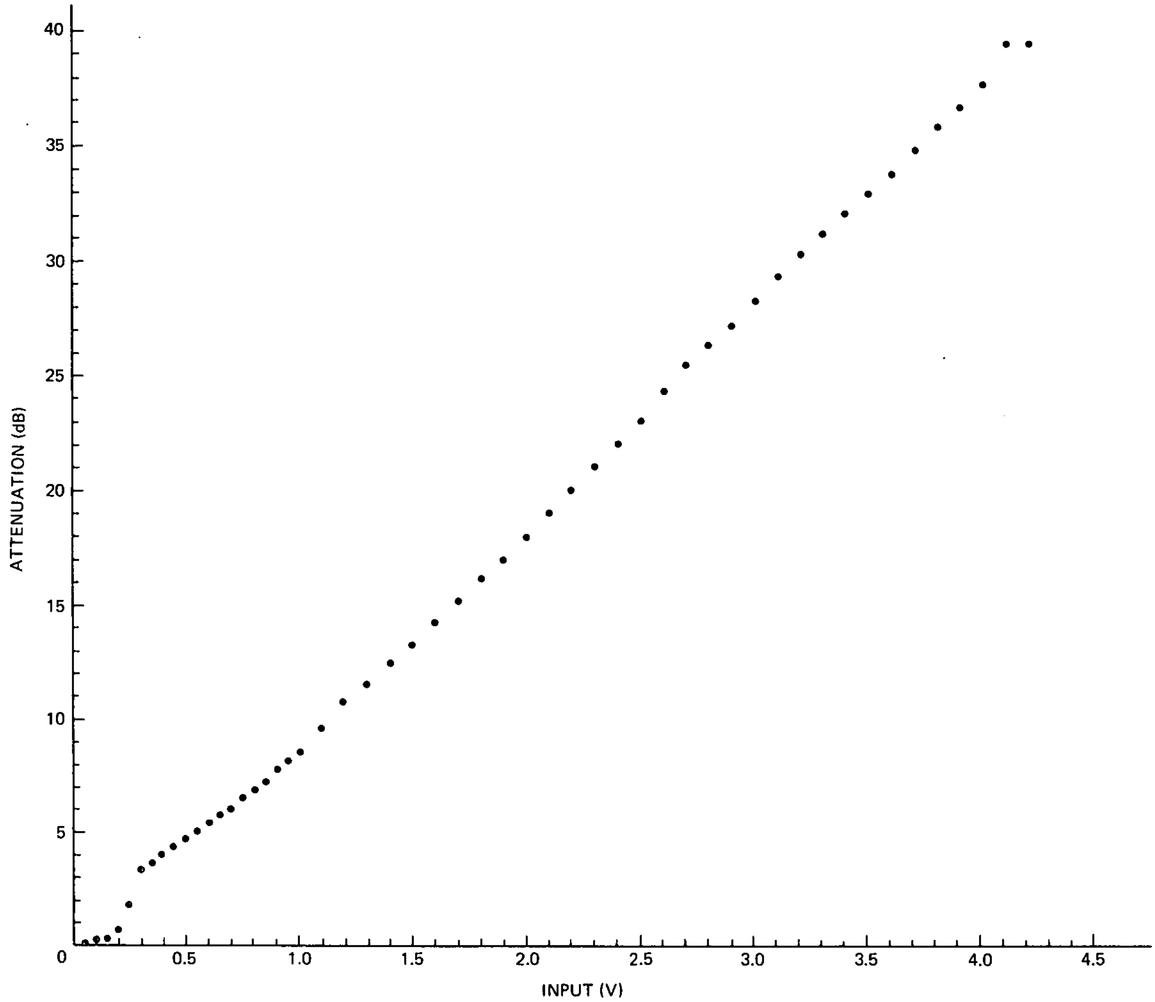


Figure 4—Typical attenuator curve.

checkout and telemetry system debugging. Also, PR data are used to evaluate the telemetry systems by supplying all possible binary combinations of data words, thus creating a situation similar to spacecraft data transmission.

4. HARDWARE SPECIFICATIONS

The significant specifications for each of the hardware components comprising the L-band telemetry system will be discussed in this section. Basically, all units were designed to meet aircraft environmental specifications in accordance with GSFC specifications 553-04-01 (see Appendix C).

L-Band Antennas

The airborne and ground L-band antennas are a matched pair specifically designed for

broad beamwidth, uniform gain characteristics. The antenna utilizes a double reentry feed and a quadrature hybrid to obtain the broad circularly polarized radiation pattern. A typical radiation pattern is shown in Figure 5. It should be noted that the effects of the aircraft and unique station environments are not included as part of this pattern. The antenna parameter values are listed below:

Operating frequency	1468.5 ± 10 MHz
Gain	3 dBi (minimum on boresight)
Polarization	left-hand circular
Axial ratio	3 dBi on boresight
	13 dBi at ±80 deg off boresight
3-dB beamwidth	150 deg nominal
Front/back	15 dB
Weight	6 lb (approximately)

L-Band Transmitter

The L-band transmitter is a spacecraft type, miniaturized, solid-state unit capable of accepting the 300-kHz digital output from the PCM commutator. The transmitter utilizes internal modules for the modulator power amplifier, multiplier RF filter, and series regulator; this enables good heat sinking and RF shielding. The basic oscillator frequency is crystal controlled, and an isolator is provided at the output stage to permit open- and short-circuit operation without damage.

The specifications were dictated by the overall system requirements and also by availability of spacecraft-qualified hardware. A list of significant parameters is given below:

Transmitter RF power	40 ± 1.0 dBm
Center frequency	1468.5 Mhz (within 0.001 percent)
RF bandwidth	3 MHz (at ±1.0 dB)
Modulator	true FM
Modulation frequency response	10 Hz to 500 kHz (at ±1.0 dB)
Carrier frequency deviation	±500 kHz (maximum)
Incidental FM	less than ±3.0 kHz
Incidental AM	less than 0.5 percent
Modulation linearity	1 percent best straight line
Spurious signals	70 dB below unmodulated carrier
Radiated leakage	less than −150 dBm (measured 2 ft from transmitter)
Coupling	ac

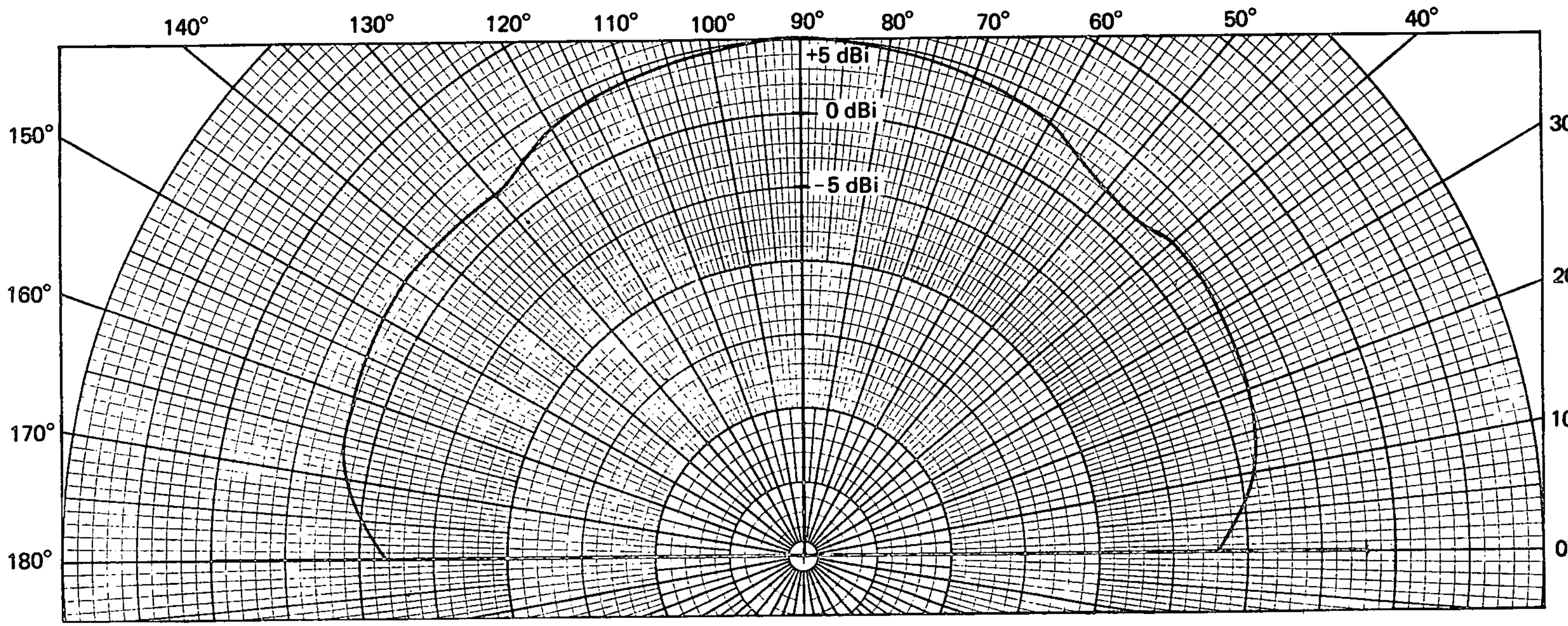


Figure 5—Antenna gain above a circular isotrope vs. elevation angle.

Power (dc)	112 W (28 V at 4 A)
Weight	2 lb
Size	5 in. X 5 in. X 1½ in.

L-Band Preamplifier

The L-band preamplifier is a stripline transistorized device. The salient parameter values are given below:

Frequency	1468.5 MHz
Noise figure	3.5 dB
Gain	25 dB
Bandwidth (3 dB)	5 MHz
Size	1½ in. X 1½ in. X 6¼ in.
Weight	1.0 lb (approximately)

L-Band Receiver

The L-band receiver is a solid-state FM receiver. The receiver utilizes double-heterodyning conversion, with the first and second mixer frequencies provided by a crystal-controlled oscillator to achieve the required frequency stability of ±50 ppm. The wideband front end has a noise figure of 10 dB. The second IF filter precedes the discriminator and is designed for a noise bandwidth of 2.2 MHz as a compromise between the significant-information sidebands and the threshold carrier-to-noise (C/N) ratio of the discriminator.

As in the case of the L-band transmitter, modularized construction is utilized, primarily to achieve RF isolation.

The significant specifications are listed below:

Frequency	1468.5 MHz (within 0.005 percent)
Noise figure	10 dB
IF bandwidth (3 dB)	2.2 MHz (nominal)
Video response	10 Hz to 500 kHz (at ±1 dB)
Video output	constant to ±2.0 dB for input levels of −60 to −100 dBm (at a given deviation)

RF Signal Controller

The RF signal controller is basically a PIN-diode diffused-junction device. When forward biased, it behaves as a resistive element over the range of frequencies of interest. By varying the diode bias current, the diode resistance can be changed from 1 Ω to 10 kΩ. The diode is used in conjunction with a control unit that varies the diode bias current, and therefore its attenuation, as a function of a dc voltage output from a computer-controlled digital-to-analog

converter. The L-band telemetry system uses two PIN diodes in cascade to achieve the required 70-dB attenuation range. A plot of attenuation vs. dc control voltage is shown in Figure 4. The significant parameter values are given below:

Maximum insertion loss	3.0 dB
Maximum attenuation range	35 dB
Linearity	±2.0 dB of best straight line
Control function	10 dB/V
Switching speed	1.0 μs
Weight	10 lb
Size	1.7 in. × 2.3 in. × 2.3 in.

PCM Commutator

The function of the PCM commutator is to format and time-division multiplex the various ground-station data required by the aircraft computer to perform network calibrations and simulations. These data are of four general types: parallel digital data, serial digital data, high-level analog data, and low-level analog data.

The parallel digital data, including the *x*- and *y*-angle readout, are obtained from the 40- and 85-ft telemetry dishes. Since these angle readouts are updated only once per second and the commutator samples these data 293 times per second, there are no sampling or data-loss problems with these data.

The serial digital data are the demodulated telemetry data from the station receivers. The frequency of these data can vary from 100 bps to 175 kbs. Therefore, provisions are made to accept the varying data rate and to ensure that there is no loss of data at the higher data rates.

The high-level analog data (±35.0 V) originate from the dish in the form of *x*- and *y*-tachometer, *x*- and *y*-error, and phase signals. The low-level analog data (±10.0 V) include the AGC levels from the station receivers and the AGC combiner units. The remaining low-level analog channels are general-purpose analog channels. The maximum frequency of these channels is 100 Hz.

The special parallel punch data are obtained in parallel from the PACT, Minitrack, and range and range-rate data punches. The maximum data rate is 150 characters per second, and the commutator has provisions for ensuring that every character is transmitted.

The PCM commutator format shown in Figure 6 meets all of the requirements for the transmission of data to the aircraft. The general output specifications for the commutator are—

Bits per word	16
Words per frame	64

64-WORD FRAME

1 FRAME-SYNC NO. 1	2 FRAME-SYNC NO. 2	3	4	5 PHASE	6	7	8
9 x-ANGLE	10	11	12	13 x-ANGLE	14	15	16
17 y-ANGLE	18	19	20	21 y-ANGLE	22	23	24
25 ERROR x / y	26	27	28	29 TACHOMETER x / y	30	31	32
33 ANALOG 1 / 2	34	35	36	37 ANALOG 3 / 4	38	39	40
41 ANALOG 5 / 6	42	43	44	45 ANALOG 7 / 8	46	47	48
49 SIGN	50	51	52	53 RARR BUFFER / HAND-OPERATED INDICATORS	54	55	56
57	58	59	60	61 PACT BUFFER / M/T BUFFER	62	63	64

Figure 6—PCM commutator telemetry-word format.

Bit rate	300 kbs
Code	split phase
Level	+8 Vdc for logic one
	−8 Vdc for logic zero
Output impedance	less than 100 Ω

The commutator word format for the serial digital data contains 15 data bits and one indicator bit, as is shown in Figure 7. The indicator bit is required since the incoming serial data can have a low data rate, and not all of the serial digital data words will be utilized. This bit will be a one when the remaining 15 bits do not contain data, and a zero when they do.

For serial data (as can be seen from Figure 6), 48 telemetry words per frame are available, with each word containing 15 bits of serial data. Thus, the total telemetry bits available are

$$48 \times 15 = 720 \text{ bits per frame.}$$

The total number of bits in a commutator frame is

$$64 \times 16 = 1024 \text{ bits per frame.}$$

The maximum possible data rate of the incoming serial digital data is therefore

$$\frac{720}{1024} \times 300\,000 = 210\,937 \text{ bps.}$$

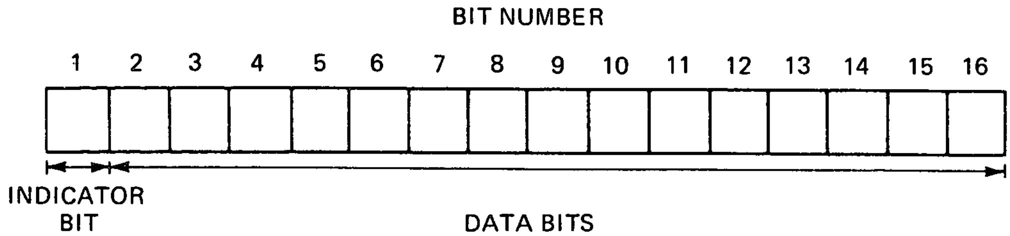


Figure 7—Typical data word. Each box represents a binary bit, logic one or logic zero.

The PCM commutator has three parallel registers which store data to ensure that no incoming serial data are lost during the transmission of the two frame-sync words or during the transmission of any other special words.

The serial digital data input is nonreturn-to-zero-level (NRZ-L) coded and, therefore, the commutator requires a clock input in phase with the serial digital data. The input levels to the commutator for both the serial digital data and the clock are logic zero (−1 to +1 Vdc) and logic one (+3 to +20 Vdc).

The parallel digital data consist of x- and y-angle readouts obtained from the 40- and 85-ft dishes. These data are commutated into words 9, 13, 17, and 21, as is shown in Figure 6. The angles are in binary-coded decimal form and are arranged in the commutator words, as is shown in Figure 8.

The high- and low-level analog channels are converted to an eight-bit (plus a sign bit) digital signal. The high-level channels (±35 V) contain x- and y-tachometer, x- and y-error, and phase signals and are contained in commutator words 5, 25, and 29. The eight low-level channels (±10 V) are AGC information and general analog channels and are contained in commutator words 33, 37, 41, and 45. The sign information for all analog channels is in commutator word 49. The bit configuration for all of the above words is shown in Figure 9.

The parallel punch data originate from the solenoid punch drivers of the PACT punch, the Minitrack punch, and the range and range-rate punch and are contained in commutator words 53 and 61, as is shown in Figure 10. These data consist of five parallel channels of serial digital data, with a maximum data rate of 150 bps. The frame-sampling rate is

$$\frac{300\,000 \text{ bits per second}}{1024 \text{ bits per frame}} = 293 \text{ frames per second.}$$

Therefore, each character of data is sampled at least once, but some characters are sampled twice.

Bits 9, 10, and 11 of word 53 (Figure 10) are logic one the first time each character is sampled. Bits 11 through 16 of word 53 are controlled by the circuitry shown in Figure 11 and are used to indicate the status of hand-operated switches (used with PACT, MOTS*, Minitrack, and so forth).

*MOTS: Minitrack Optical Tracking System.

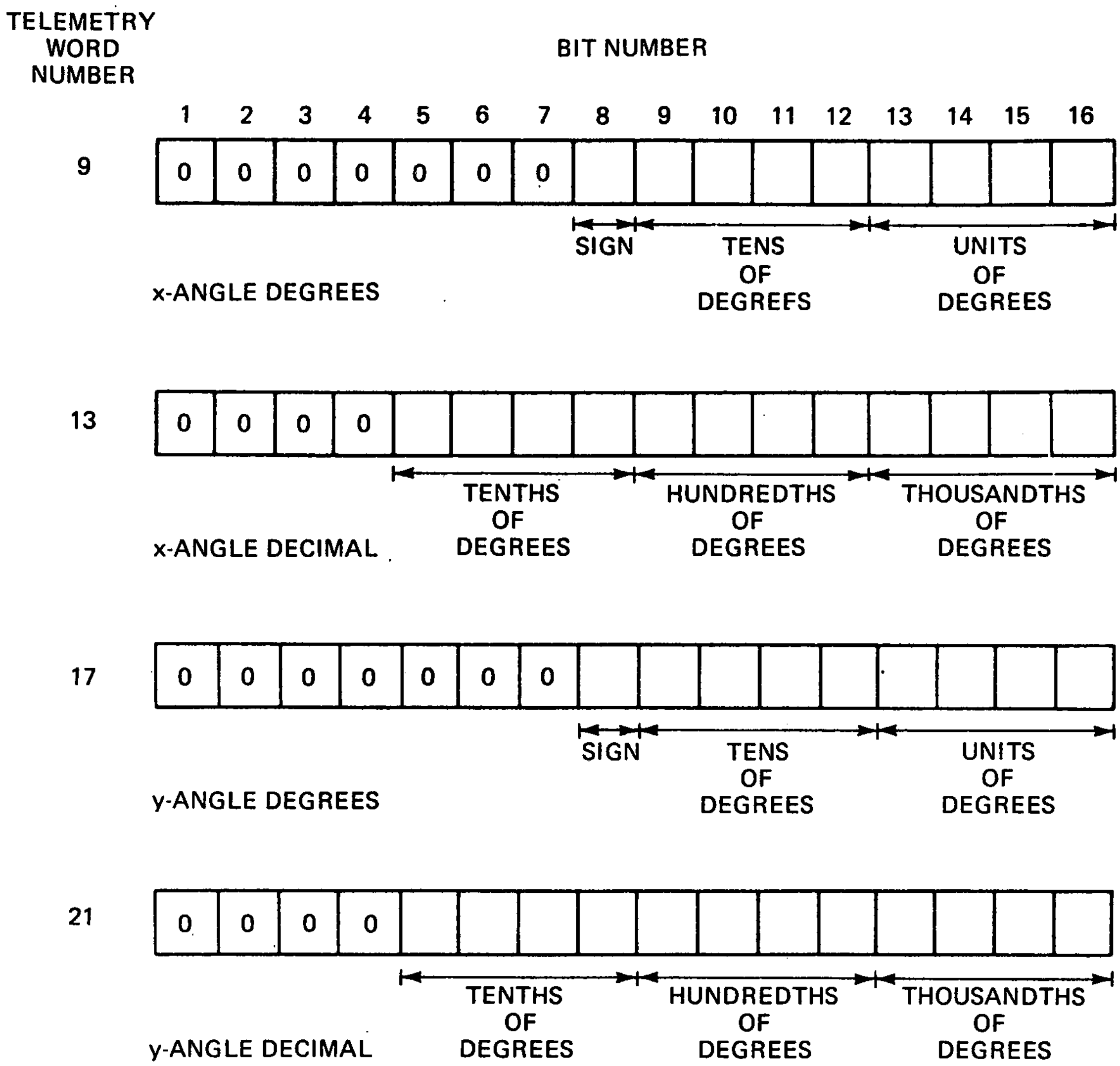


Figure 8—Telemetry format, words 9, 13, 17, and 21.

The general construction of the PCM commutator is shown in Figure 12. The commutator is a self-contained unit requiring only ac power and the desired input signals. The unit is mounted in a fiberglass carrying case, the top of which is removable to expose all of the controls and input connectors. The commutator also allows any word of the format to be displayed on front-panel indicator lights.

Airborne Decommutation System

The function of the airborne decommutation system (ADS) is to accept serial PCM data from the L-band uplink system, then condition, synchronize, and format these data and present them in parallel form to the airborne computer for analysis.

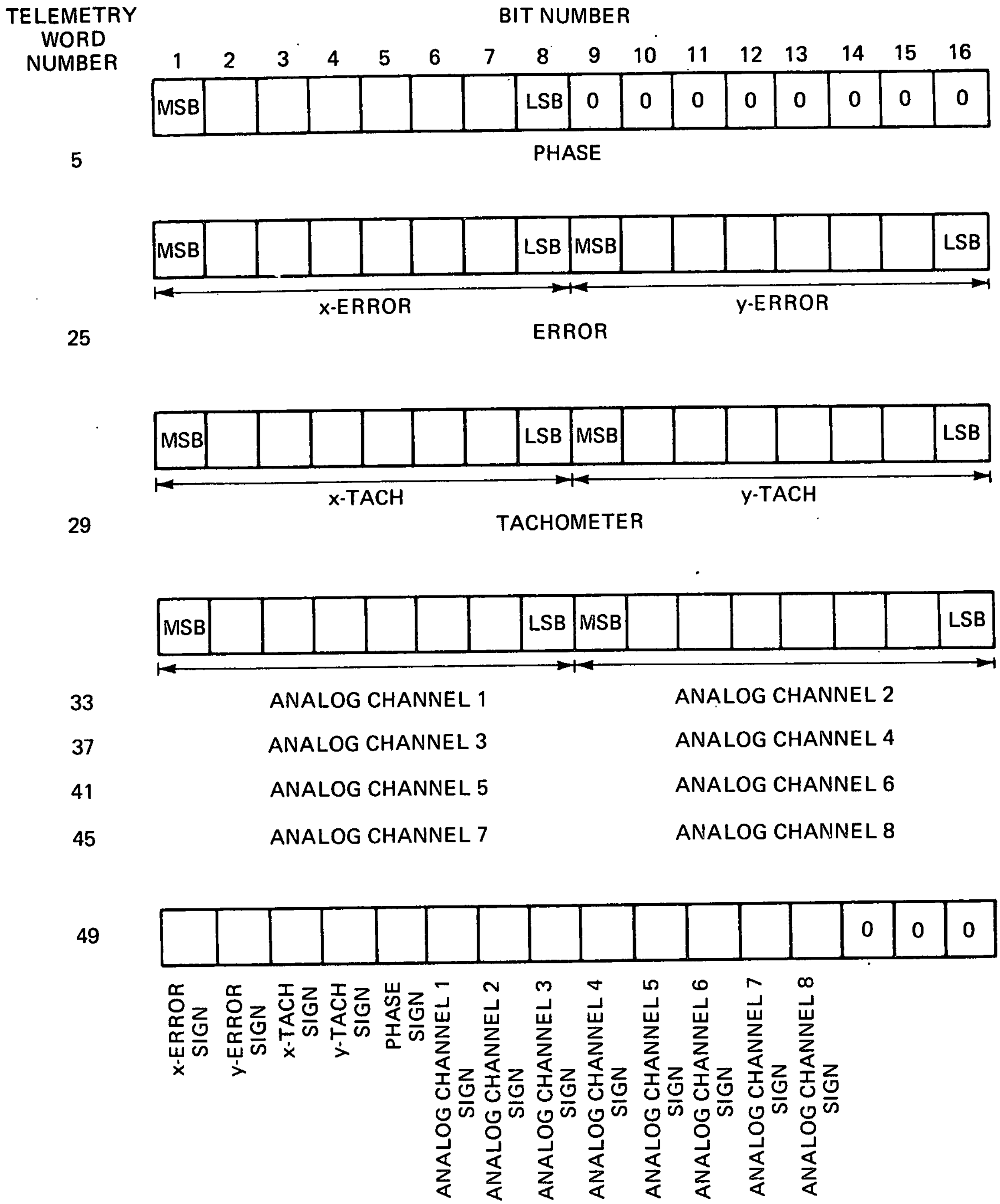


Figure 9—Telemetry format, words 5, 25, 29, 33. 37. 41. 45, and 49.

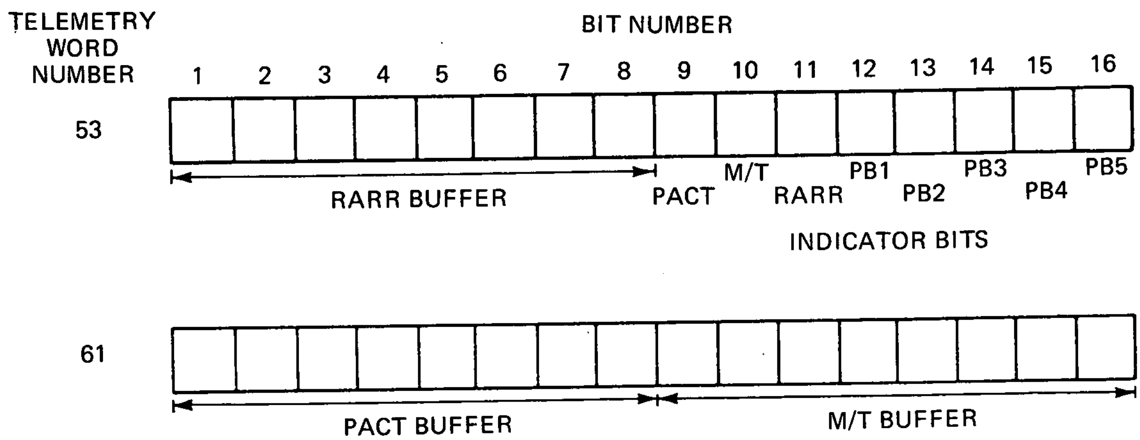


Figure 10—Telemetry format, words 53 and 61.

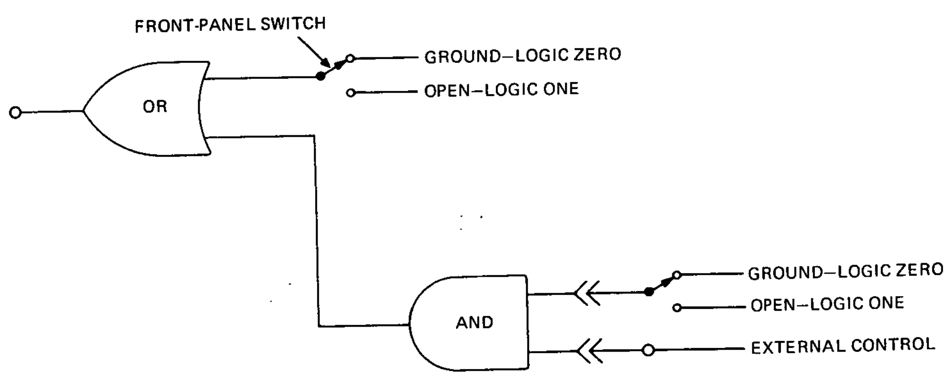
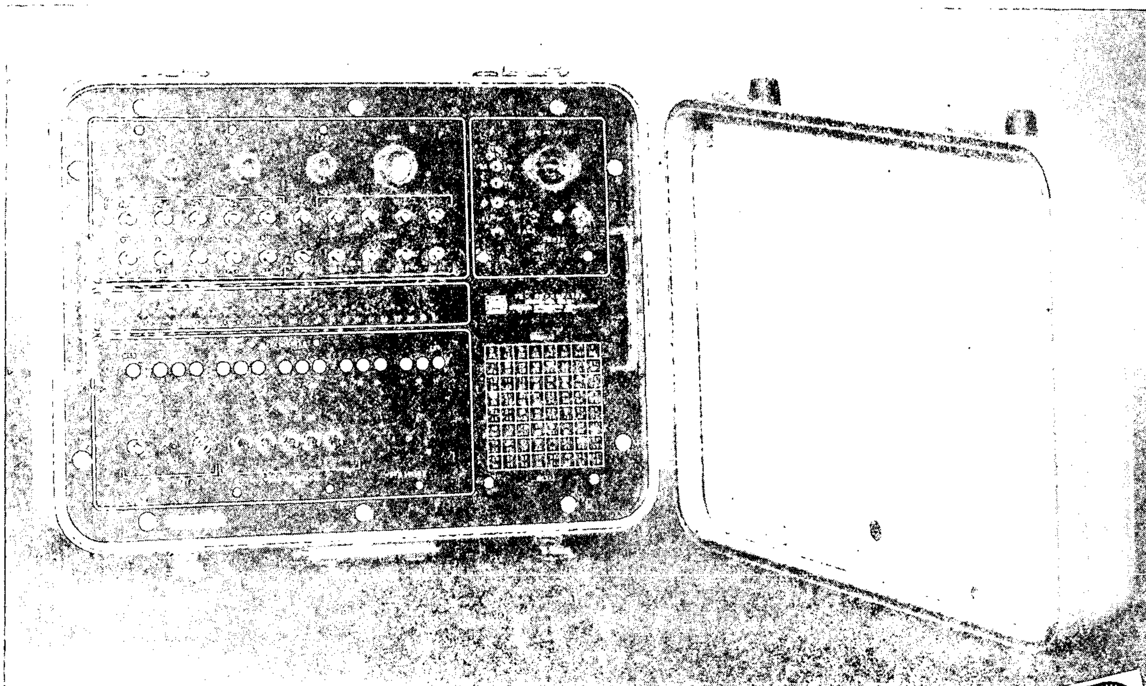


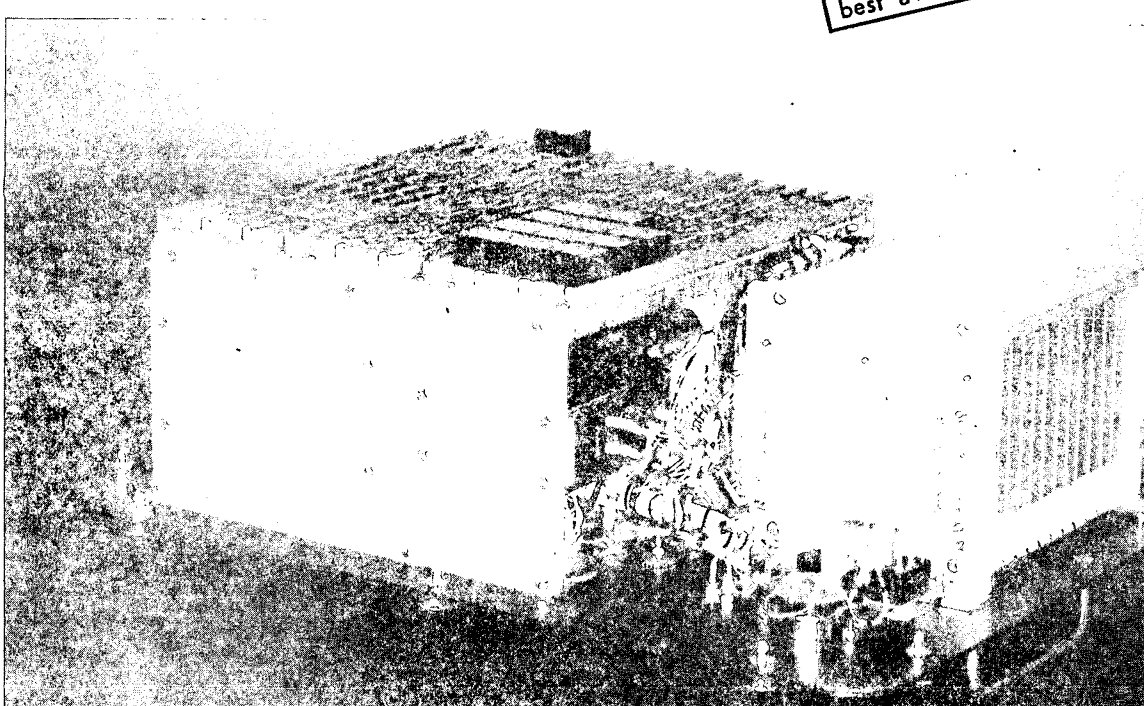
Figure 11—Control circuit for telemetry word 53, bits 12 through 16.

The ADS consists of a PCM bit synchronizer and signal conditioner, a PCM frame decommutator, and an ADS computer interface. The PCM bit synchronizer and signal conditioner accepts a preselected PCM code and provides signal conditioning, bit detection, and code conversion. The salient specifications of the bit synchronizer are as follows:

Bit rate	1 to 1.2 Mbs
Input codes	NRZ-L and split phase
Input level	0.5 to 60 V with AGC and offset control
Error rate	within 1 dB of theoretical wave to 0-dB signal-to-noise (S/N) ratio
Synchronization	within 90 deg at 0-dB S/R ratio
Acquisition	±10 percent of bit-rate setting
Tracking	±20 percent of bit-rate setting



(a)



(b)

Figure 12—PCM commutator: (a) portable carrying case; (b) inside view.

Data output	NRZ-L or split-phase polarity switchable
Clock output	Synchronous four phases

The PCM frame decommutator accepts conditioned NRZ-L and synchronous clock data in serial form and synchronizes its output data with the uplink PCM commutator by recognizing predetermined patterns in the data. The formatted output data and their associated timing pulses are then presented to the ADS computer interface. A buffer mode is available in which the decommutator acts only as a buffer and presents the unformatted data to the interface. Also, an analog output representing any preselected word per frame is available for strip-chart presentation. The salient specifications of the decommutator are as follows:

Bit rate	1 to 1.6 Mbs
Syllable length	2 to 64 bits
Word length	1 to 8 syllables
Frame length	2 to 512 words
Outputs	16 bits parallel data
	9 bits word count
	word and syllable rate pulses
	frame lock signal
	analog (0 to 10 V at 1 mA)

The ADS computer interface accepts parallel PCM and word-count data from the decommutator. There are two methods for inputting data to the computer: the standard input, and the direct multiplex control (DMC) option.

For standard input, the computer must recognize and process data on each interrupt from the interface, whereas in DMC, the computer transfers data between preselected memory locations and the interface with a minimum of program control. Three modes of operation are available in both the standard input and the DMC option. These are the normal mode, in which every word from the decommutator causes an interrupt to be generated; the flag mode, in which only words with a zero in bit 1 will cause an interrupt to be generated; and the special word (SW) mode, in which any of eight preselected words per frame will cause an interrupt to be generated. The flag and SW modes may be used concurrently.

A DMC autoswitch mode is available. When one block of memory locations is filled, the computer automatically switches to another. This allows the computer to process one block of data while loading another.

Airborne Telemetry Simulator

The telemetry simulator used with the airborne computer generates simulated telemetry data for station bit-error rate tests, satellite simulation, and any special tests requiring PCM data. The simulator includes a control panel which provides the means to control the charac-

teristics of the PCM pulse train constructed by the interface logic. The basic simulator specifications are–

Bit rate	10 to 1.4 Mbs
Output codes	NRZ-L, split-phase-L, and RZ, polarity reversible
Output amplitude	0 to 10 V with ±10-V offset

5. TASP SOFTWARE MODULES

The TASP software system modules, with the aircraft equipment in a telemetry test operation configuration, are block diagrammed in Figure 13. This section discusses the function of the significant software modules in the TASP software system.

AGC Precal

The AGC precal software module establishes and stores a table of the ground-station receiving system input signal level vs. AGC voltage. The method for obtaining the AGC precalibration data is shown in Figure 14. A known signal level is inserted into the test injection system by a calibration transmitter and decremented in 5-dB steps over the signal range of interest (usually −80 dBm to −140 dBm). This operation is voice communicated between the aircraft computer operator and the ground-station test conductor. The ground telemetry receiver AGC voltage is digitized by the PCM commutator and transmitted to the computer by the L-band link.

For each signal level, the computer program accepts 1000 samples of the digitized AGC information, computes the average and standard deviation, and outputs the results to the automatic send-and-receive (ASR) typewriter. This AGC information is stored in the computer for use by other TASP modules and punched on paper tape as backup data. A typical AGC precal is shown in Figure 15. The signal level is in dBm and the average AGC (AVG. AGC) and the standard deviation (STD. DEV.) are in quanta.

RF Calculate

The RF calculate software module determines the theoretical bit-error rate for the system under test and operating values (C1 to C6) to be used in the real-time portion of TASP. Input parameters (shown in Figure 16) and the link configuration for each network station are stored on magnetic tape. (Typical link configuration parameters for the Rosman, North Carolina, station are shown in Figure 17.) These data may be updated or revised by the computer operator on the ASR typewriter. The RF calculate results are printed on a high-speed electrolytic printer, as is shown in Figure 18. The symbols used in the printout are explained below:

LEVEL	= input signal level, in dBm.
P. ERROR	= probability of error.

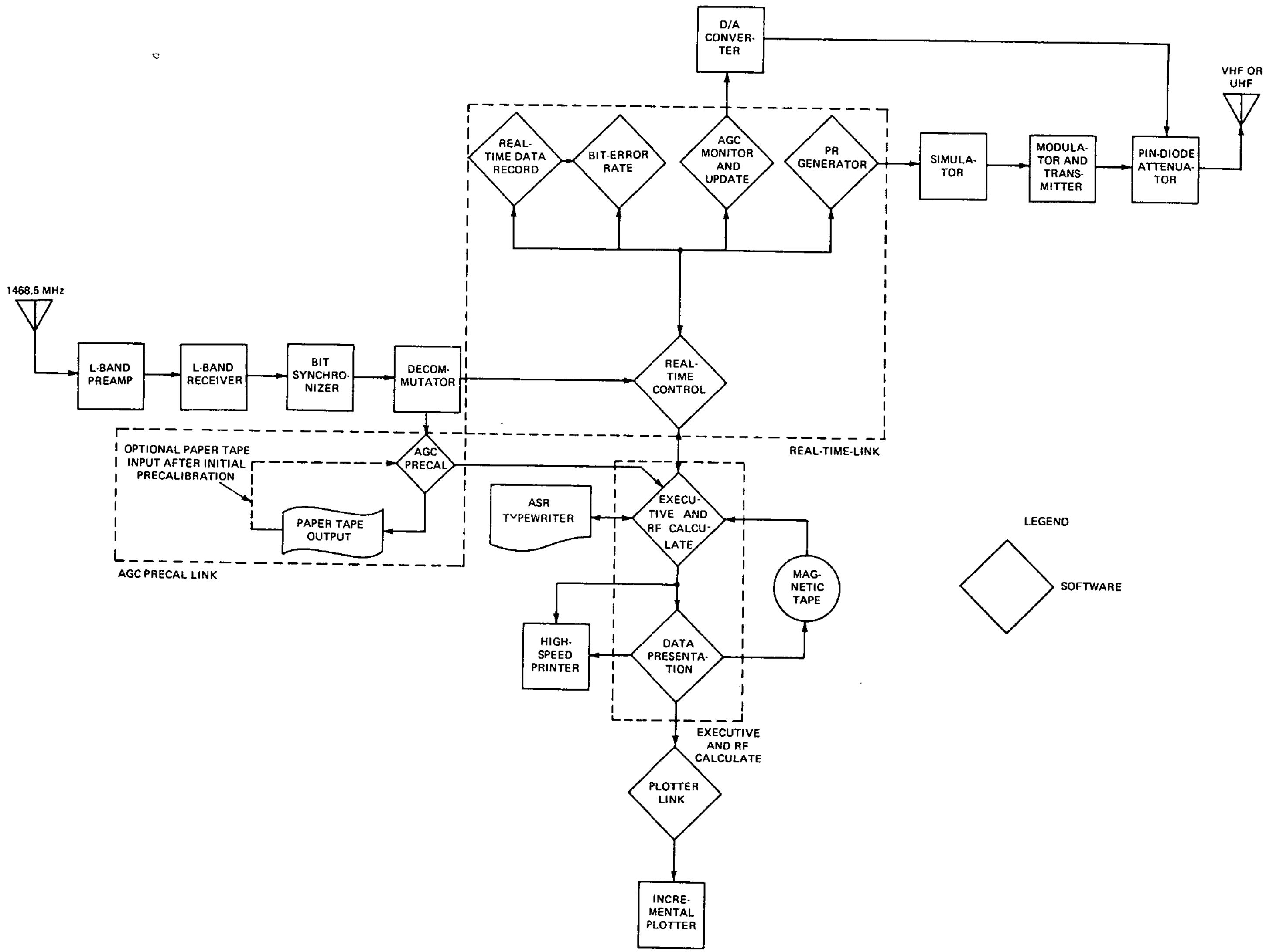


Figure 13—TASP software system.

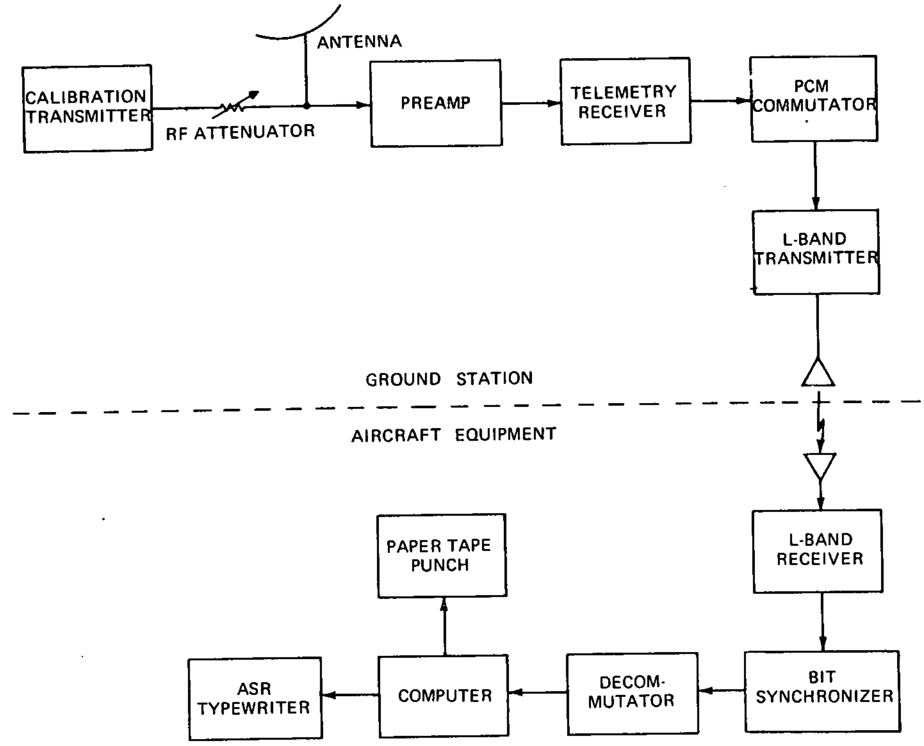


Figure 14—AGC precal equipment configuration.

AGC	=	input signal strength, expressed in digital quanta.
C1 to C6	=	operating values used in the real control portion acquisition and maintenance of the real-time signal, in quanta.
TA	=	antenna temperature, in K.
TS	=	system temperature, in K.
N/B	=	noise per unit bandwidth, in dBm per cycle.
TYPE RT START, STOP, INCR?	=	desired starting signal level, desired stopping signal level, and the increments, in dB.

Real-Time Link

The real-time link software module has four functions: (1) to maintain a specified received signal level, (2) to generate and transmit a PR data stream, (3) to collect and store incoming telemetry data, and (4) to perform a bit-error rate calculation on the stored data and output the results. The equipment configuration used to perform these functions is shown in Figure 19. The maintenance of a desired signal level is accomplished by the use of the operating values C1 to C6, obtained from the RF calculate portion of the program, and several input parameters (numbers 28 to 37 in Figure 16). The computer has the received AGC available through the PCM commutator and the decommutator. This actual AGC word

```
SET SENSE SWITCH 1 TO END CALIBRATION

*SIGNAL LEVEL(DBM) = 100
 SIGNAL LEVEL = 100     AVG. AGC =  63    STD. DEV. =  1

*SIGNAL LEVEL(DBM) = 105
 SIGNAL LEVEL = 105     AVG. AGC =  31    STD. DEV. =  1

*SIGNAL LEVEL(DBM) = 110
 SIGNAL LEVEL = 110     AVG. AGC =   0    STD. DEV. =  1

*SIGNAL LEVEL(DBM) = 115
 SIGNAL LEVEL = 115     AVG. AGC = -31    STD. DEV. =  1

*SIGNAL LEVEL(DBM) = 120
 SIGNAL LEVEL = 120     AVG. AGC = -63    STD. DEV. =  2

*SIGNAL LEVEL(DBM) = 125
 SIGNAL LEVEL = 125     AVG. AGC. = -90   STD. DEV. =  2

*SIGNAL LEVEL(DBM) = 130
 SIGNAL LEVEL = 130     AVG. AGC = -118   STD. DEV. =  4

*SIGNAL LEVEL(DBM) = 135
 SIGNAL LEVEL = 135     AVG. AGC = -146   STD. DEV. =  6

*requested by operator
```

Figure 15—Typical AGC precal.

is compared with the desired AGC, and an error value is calculated. This value is converted to a digital word which, when outputted to the PIN-diode attentuator interface, changes the attenuation to bring the AGC of the ground telemetry receiver to the desired signal level. Since the commutator sampling rate is 3 ms/frame and the AGC speed of the receiver is usually 30 ms, the program must wait for 10 frames of commutator data before again sampling the actual AGC word to determine if the desired effect was achieved. If the desired AGC is not obtained, the procedure is repeated until the actual AGC is within C2 quanta of the AGC desired or until the procedure has been repeated 10 times. If the AGC received does not fall within the required limits during the 10 attempts, an error message ("NO ACQUISITION") is typed on the ASR typewriter. If acquisition is successful, the program monitors the actual AGC word and applies corrective signals to the PIN-diode attenuators to maintain the actual AGC within C3 (which precludes loss of signal tracking from extraneous noise spikes). If the actual AGC differs from the AGC desired by C3 quanta for C6 consecutive samples, another error message is sent to the ASR ("LOST TRACK"). At this point, the test can be restarted or advanced to the next desired signal level.

CHECK SENSE SWITCHES
STA ID 15
LINK #1
SEQ #1
PARAMETER INPUT

1. – NG	NOISE SOURCES
2. – A	CHANNEL
3. – AC	OPERATING MODE
4. – 70.000	FARNHT SIA TEMP
5. – 136. 000	FREQUENCY (M-HZ)
6. – 21. 000	ANTENNA GAIN
7. – 1. 000	ANT ECCENTRICITY
8. – . 500	LINE LOSS
9. – 1. 000	FILTER LOSS
10 – 4. 000	PREAMP NOISE FIG
11 – 31. 500	PREAMP GAIN
12 – . 000	CONVTR NOISE FIG
13 – . 000	CONVERTER GAIN
14 – . 000	CONVTR INP VSWR
15 – 5. 000	MCPLR NOISE FIGR
16 – . 000	MULTICPLE GAIN
17 – 6. 000	RCVR NOISE FIGURE
18 – PM	MODULATION TYPE
19 – 1. 000	MODULATION INDEX
20 – 9998. 998	BIT RATE
21 – SPL	PCM TYPE
22 – 99999 99	RECEIVR IF BDWTH
23 – 49999 99	DEMODULATOR BWDTH
24 – 3. 000	COMB IMPROV FCTR
25 – 2. 000	INTEGRATOR BWDTH
26 – . 940	INTEGRATN PERIOD
27 – 71	TWO DIGIT YEAR
28 – . 030	AGC SPEED
29 – . 117	PIN DIODE SLP K2
30 – . 117	K2′
31 – 5. 000	C2, C3 FDB FCTR X
32 – 3. 000	C4 IF SNR GT 6
33 – 2. 000	C4 IF SNR GT 2
34 – 1. 000	C4 IF SNR LT 2
35 – 4. 000	C6 IF SNR GT 6
36 – 3. 000	C6 IF SNR GT 2
37 – 2. 000	C6 IF SNR LT 2
38 – . 000	SPARE INPUT
39 – 5. 000	REGISTER LENGTH
40 – 2. 000	FEEDBACK STAGE
41 – 15. 000	OUTPUT LENGTH
42 – . 052525	BIT PATTERN

Figure 16–Typical input parameter list.

PARAMETER		Link #1 Freq. 136			Link #2 Freq. 400			Link #3 Freq. 1700			Link #4 Freq. 136			Link #5 Freq. 400		
		Model	Nom.	Meas.	Model	Nom.	Meas.	Model	Nom.	Meas.	Model	Nom.	Meas.	Model	Nom.	Meas.
Ant. Gain (dB)		85′-1	27.6		85′-1	35.6		85′-1	47.7		85′-2	27.6		85′-2	35.6	
Ant. Eccentricity		85′-1	1:1		85′-1	1:1		85′-1	1:1		85′-2	1:1		85′-2	1:1	
Line Loss (dB)			0.5			0.5			0.5			0.5			0.5	
Filter Loss (dB)		RANTEC	1.0			0.0			0.0		RANTEC	1.0			0.0	
P/A Input VSWP	S1	SSP-S102	1.2:1		AIL P/A-CONV	1.1:1		AIL P/A-CONV	1.21:1		SSP-S102	1.2:1		AIL P/A-CONV	1.1:1	
	S2		1.2:1			1.1:1			1.21:1			1.2:1			1.1:1	
	DIV		1.2:1			1.1:1			1.21:1			1.2:1			1.1:1	
P/A NF (dB)	S1		4.0			1.8±0.1			2.1±0.1			4.0			1.8±0.1	
	S2		4.0			1.8±0.1			2.1±0.1			4.0			1.8±0.1	
	DIV		4.0			1.8±0.1			2.1±0.1			4.0			1.8±0.1	
P/A Gain (dB)	S1		31.5±3.5			30.0±2.0			27.0±3.0			31.5±3.5			30.0±2.0	
	S2		31.5±3.5			30.0±2.0			27.0±3.0			31.5±3.5			30.0±2.0	
	DIV		31.5±3.5			30.0±2.0			27.0±3.0			31.5±3.5			30.0±2.0	
Converter NF (dB)	SUM		0.0			0.0			0.0			0.0			0.0	
	DIV		0.0			0.0			0.0			0.0			0.0	
Conv. Gain (dB)	SUM		0.0			0.0			0.0			0.0			0.0	
	DIV		0.0			0.0			0.0			0.0			0.0	
Conv. Input VSWR	SUM		0.0			0.0			0.0			0.0			0.0	
	DIV		0.0			0.0			0.0			0.0			0.0	
M/C NF (dB)	SUM	MC-4137-6	6.0		MC-4137-6	6.0		MC-4137-6	6.0		MC-4135-6	5.0		MC-4135-6	5.0	
	DIV		6.0			6.0			6.0			5.0			5.0	
M/C Gain (dB)	SUM		0±1.0			0±1.0			0±1.0			0±1.0			0±1.0	
	DIV		0±1.0			0±1.0			0±1.0			0±1.0			0±1.0	
M/C Input VSWR	SUM		1.5:1			1.5:1			1.5:1			1.5:1			1.5:1	
	DIV		1.5:1			1.5:1			1.5:1			1.5:1			1.5:1	
Rcvr NF (dB)	SUM	GD/E	6.0		GD/E	6.0		GD/E	6.0		GD/E	6.0		GD/E	6.0	
	DIV		6.0			6.0			6.0			6.0			6.0	

Figure 17—Log of typical link configuration parameters for the Rosman station.

LEVEL (DBM)	SNR (DB)	P. ERR.
-116. 0	12. 710	. 000008
-117. 0	11. 710	. 000050
-118. 0	10. 710	. 000300
-119. 0	9. 7104	. 001112
-120. 0	8. 7104	. 003206
-121. 0	7. 7104	. 007559
-122. 0	6. 7104	. 015182
-123. 0	5. 7104	. 026813
-124. 0	4. 7104	. 042719
-125. 0	3. 7104	. 062647
-126. 0	2. 7104	. 085935
-127. 0	1. 7104	. 111679
-128. 0	. 7104	. 138910

LEVEL	AGC	C1	C2	C3	C4	C5	C6
-118; 0	-50. 0	1335. 0	28. 0	37. 0	1. 0	8. 0	2. 0
-119. 0	-56. 0	1335. 0	31. 0	42. 0	1. 0	8. 0	2. 0
-120. 0	-63. 0	1583. 0	30. 0	47. 0	1. 0	8. 0	2. 0
-121. 0	-68. 0	1583. 0	33. 0	53. 0	1. 0	8. 0	2. 0
-122. 0	-73. 0	1583. 0	37. 0	59. 0	1. 0	8. 0	2. 0
-123. 0	-79. 0	1583. 0	42. 0	66. 0	2. 0	7. 0	3. 0
-124. 0	-84. 0	1583. 0	47. 0	75. 0	2. 0	7. 0	3. 0
-125. 0	-90. 0	1526. 0	55. 0	84. 0	2. 0	7. 0	3. 0
-126. 0	-95. 0	1526. 0	61. 0	94. 0	2. 0	7. 0	3. 0
-127. 0	-101. 0	1526. 0	69. 0	105. 0	3. 0	6. 0	4. 0
-128. 0	-106. 0	1523. 0	77. 0	118. 0	3. 0	6. 0	4. 0

TA = 280
TS = 723. 6239
N/B = -170. 004 ?-169.
TYPE RT START, STOP, INCR ? 118, 128, 1

Figure 18—Typical RF calculate output table.

If the signal level corrections are successful, the program continues to update the attenuators while generating and receiving PR data and performing a bit-error rate analysis. When the processing of PR data is completed, the signal level portion of the real-time program proceeds to the next desired signal level, and the acquisition and tracking processes are repeated. The starting signal level (in dBm), stopping signal level (in dBm), and incrementation (in dB) are part of the input parameters to the RF calculate portion of the program.

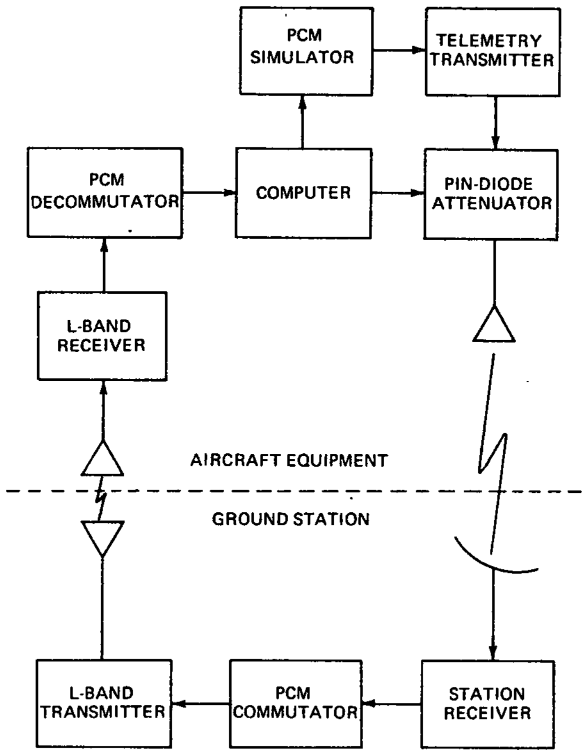


Figure 19—Real-time link equipment configuration.

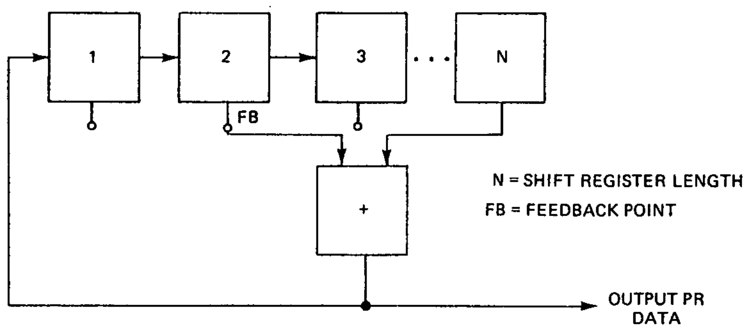


Figure 20—PR data generator.

The generation of PR data is done by the method shown in Figure 20, where the length of the shift register and the feedback point are specified in the input parameters (numbers 39 and 40 of Figure 16). The maximum shift register length is 15, and the minimum is four. Any feedback point is acceptable; however, only maximal length patterns are used for testing purposes. After execution of the RF calculate module and prior to the signal level monitor

module execution, a set of PR data is generated and stored in the computer. After the signal level monitor portion of TASP has acquired the desired signal level, the real-time program transmits these PR data to the ground station by the PCM simulator and a selected airborne telemetry transmitter. After these data have been received, demodulated, and bit synchronized by the ground station, they are transmitted to the computer by the PCM commutator, L-band transmitter, receiver, and decommutator. The program stores the retransmitted data until 100 000 bits have been received.

These stored data are then analyzed to determine the logic ones and logic zeros and the total error rate. This analysis is performed in the following manner: The data are divided into 10 groups of 10 000 bits each, and each group is analyzed separately. The first 15 bits of a group of 10 000 bits are used, and from there, a PR code is generated and compared with the next 50 stored bits. If the error rate of these 50 bits is less than 15 percent, the generated PR data are said to be synchronized with the stored PR data. Due to the shape of the autocorrelation function for PR data, the probability of obtaining a false synchronization is small. If the error rate of the 50 bits is greater than 15 percent, the next 15 bits of stored data are used to generate a PR pattern. If the process is repeated five times without obtaining synchronization, an error message is sent to the ASR ("NO LOCK UP"). At this time, the test can be re-initiated, or the operator can advance to another signal level. If synchronization is obtained, the remaining 10 000 bits are analyzed. When the first 10 000-bit sample is finished, the process is repeated for the next nine sets of data. When complete, a summary of the analysis is printed by the high-speed printer (Figure 21). Then, the signal level monitor portions of the program are instructed to acquire the next received signal level.

Data Presentation

The function of the data presentation software module is to present the results of the bit-error analysis and the RF calculate in a readily understandable format. This is accomplished by using the high-speed printer to output these results in a tabular form, as is shown in Figure 22. This table contains the signal level, the theoretical noise spectral density (ϵ/N), the theoretical error rate, and the actual error rate obtained for each signal level and each 10 000-bit sample.

The curves of theoretical error rate and actual error rate vs. input signal strength are plotted on a digital plotter, as is shown in Figure 23. For each signal level, each of the ten 10 000-bit samples is plotted as a point, and the average error rate (corrected to eliminate all points outside the 3σ limit) is plotted as a square. This curve and its deviation from the theoretical error curve is a measure of the performance of the system.

6. TEST RESULTS

The first field testing of this system was accomplished at the Network Test and Training Facility in November 1970 to determine the characteristics of the L-band ground-to-air transmission system. The L-band transmitter was modulated with 300-kbs split-phase data

SGL LVL = -118

* 0	** 0
0	0
0	1
0	1
0	0
1	1
0	0
0	2
0	0
0	1

SGL LVL = -119

0	1
0	0
0	0
5	2
21	7
2	3
1	1
4	0
1	2
1	0

SGL LVL = -120

2	1
2	0
0	0
1	0
2	0
0	0
1	2
2	0
1	1
0	0

SGL LVL = -121

3	3
2	0
5	1
4	0
3	2
1	2
4	1
1	2
3	0
2	0

SGL LVL = -122

19	5
24	8
21	9
38	17
61	34
61	42
81	39
98	37
119	57
118	75

SGL LVL = -123

39	16
37	17
48	13
33	19
34	18
51	10
44	17
31	8
26	16
29	17

SGL LVL = -124

61	37
72	30
56	39
59	34
68	24
54	25
54	35
64	20
58	33
45	35

SGL LVL = -125

146	72
145	95
158	66
135	93
133	80
121	73
166	75
124	68
151	74
145	80

SGL LVL = -126

227	142
220	132
186	135
216	152
210	118
219	125
225	117
217	128
200	103
204	130

SGL LVL = -127

309	226
292	201
299	214
333	226
276	205
295	216
272	189
267	182
269	184
285	180

SGL LVL = -128

376	246
375	270
384	317
363	273
361	251
342	231
265	221
341	225
357	249

* 1 errors
** 0 errors

Figure 21—Typical real-time data summary.

DBM	E/S(DB)	SNR(DB)	P. ERR.	PASS	ERROR	1'S ERR
-116. 0	11. 50	12. 71	. 000008			
-117. 0	10. 50	11. 71	. 000059			
-118. 0	9. 50	10. 71	. 000300	1.	. 000000	000000
				2.	. 000000	000008
				3.	. 000100	000100
				4.	. 000100	000100
				5.	. 000000	000000
				6.	. 000200	000100
				7.	. 000000	000000
				8.	. 000200	000200
				9.	. 000000	000000
				10	. 000100	000100
				1-10	. 000070	000060
-119. 0	8. 50	9. 71	. 001112	1.	. 000100	000100
				2.	. 000000	000000
				3.	. 000000	000000
				4.	. 000700	000200
				5.	. 002799	000700
				6.	. 000500	000300
				7.	. 000200	000100
				8.	. 000400	000000
				9.	. 000300	000200
				10	. 000100	000000
				1-10	. 000510	000160
-120. 0	7. 50	8. 71	. 000206	1.	. 000300	000100
				2.	. 000200	000000
				3.	. 000000	000000
				4.	. 000100	000000
				5.	. 000200	000000
				6.	. 000000	000000
				7.	. 000300	000200
				8.	. 000200	000000
				9.	. 000200	000100
				10	. 000000	000000
				1-10	. 000150	000040
-121. 0	6. 50	7. 71	. 007559	1.	. 000600	000300
				2.	. 000200	000000
				3.	. 000600	000100
				4.	. 000400	000000
				5.	. 000500	000200
				6.	. 000300	000200
				7.	. 000500	000100
				8.	. 000300	000200
				9.	. 000300	000000
				10	. 000200	000000
				1-10	. 000390	000110
-122. 0	5. 50	6. 71	. 015182	1.	. 002399	000500
				2.	. 003198	000800
				3.	. 002999	000900
				4.	. 005497	001699
				5.	. 009495	003398
				6.	. 010295	004198
				7.	. 011994	003898
				8.	. 013493	003698
				9.	. 017591	005697
				10	. 019290	007496
				1-10	. 009625	003228
-123. 0	4. 50	5. 71	. 026813	1.	. 005497	001599
				2.	. 005397	001699
				3.	. 006097	001299
				4.	. 005197	001899
				5.	. 005197	001799

Figure 22—Typical data presentation sheet.

DBM	E/S(DB)	SNR(DB)	P. ERR.	PASS	ERROR	1'S ERR
				6.	.006097	000999
				7.	.006097	001699
				8.	.003898	000800
				9.	.004198	001599
				10	.004598	001699
				1-10	.005227	001509
-124.0	3.50	4.71	.042719	1.	.009795	003698
				2.	.010195	002999
				3.	.008496	002899
				4.	.008296	002399
				5.	.009195	002399
				6.	.007896	002499
				7.	.008896	003498
				8.	.008396	001999
				9.	.009095	003298
				10	.007996	003498
				1-10	.008826	002919
-125.0	2.50	3.71	.062647	1.	.021789	007196
				2.	.023988	009495
				3.	.022389	006597
				4.	.019790	006297
				5.	.021289	007996
				6.	.019390	007296
				7.	.024088	007496
				8.	.019190	006797
				9.	.022489	007396
				10	.022489	007996
				1-10	.021689	007456
-126.0	1.50	2.71	.085935	1.	.036882	014193
				2.	.035182	013193
				3.	.032084	013493
				4.	.036782	015192
				5.	.032784	011794
				6.	.034383	012494
				7.	.034183	011694
				8.	.034483	012794
				9.	.030285	010295
				10	.033383	012994
				1-10	.034043	012814
-127.0	.50	1.71	.111679	1.	.051474	020590
				2.	.049275	020090
				3.	.051274	021389
				4.	.053873	020590
				5.	.048076	020490
				6.	.051074	021589
				7.	.046077	018891
				8.	.044878	018191
				9.	.045277	018391
				10	.044478	015992
				1-10	.048576	019620
-128.0	-.50	.71	.138910	1.	.062169	024588
				2.	.064468	026987
				3.	.070065	031684
				4.	.063568	027286
				5.	.061169	025087
				6.	.057271	023088
				7.	.048576	022089
				8.	.056572	022489
				9.	.060570	024888
				10	.066267	025587
				1-10	.061069	025377
-129.0	-1.50	-.29	.166719			

Figure 22 (concluded)—Typical data presentation sheet.

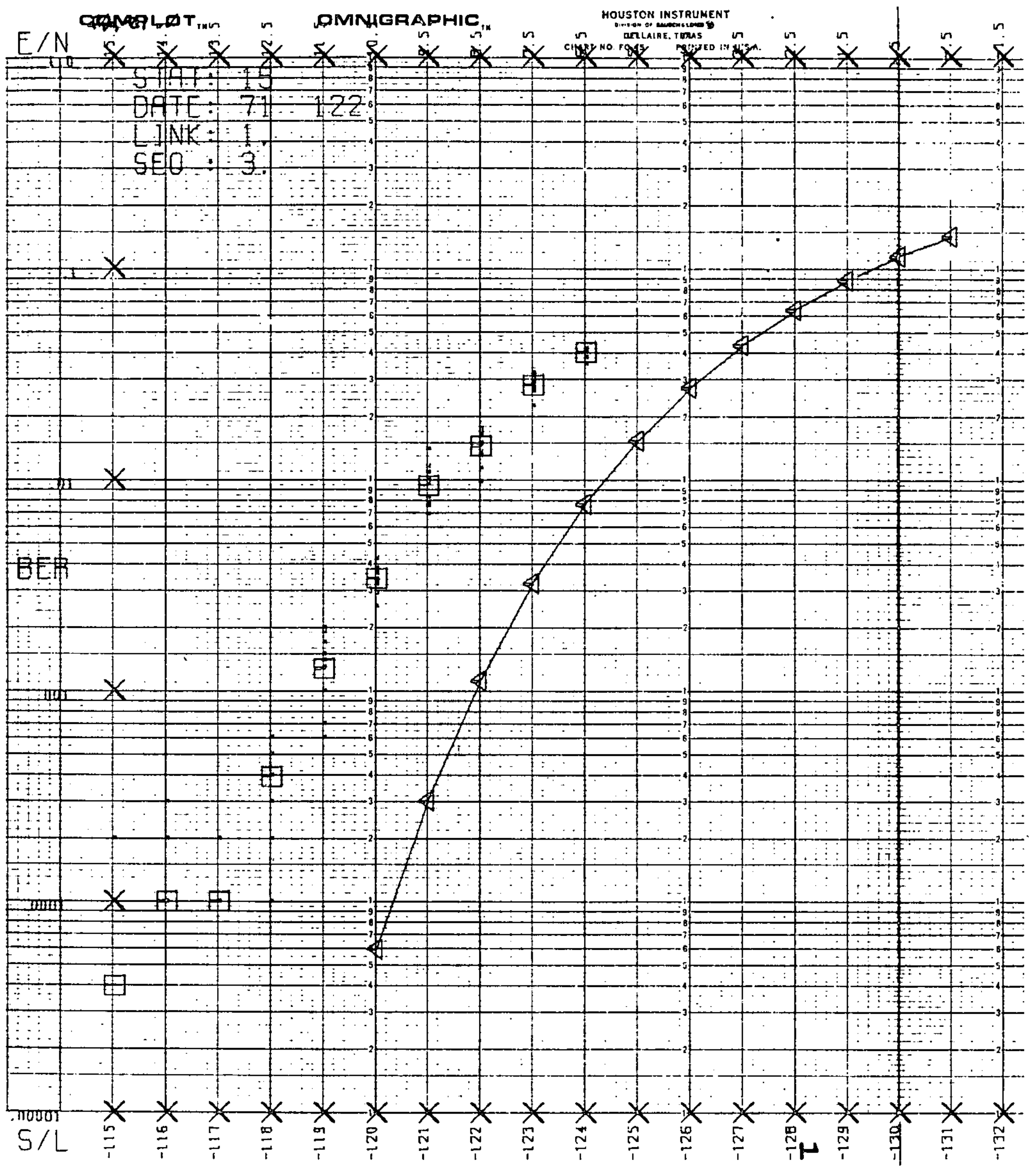


Figure 23—Sample plot of theoretical and measured bit-error-rate curves.

by a PR data generator. These data were transmitted to the airplane and demodulated by the L-band receiver, and an error analysis was performed on the data. The data were found to be essentially error free for all aircraft attitudes, at ranges up to 10 miles, and during a test period of approximately 2 hours.

The second field test of this system was at the Fort Myers, Florida, station in December 1970. The purpose of this test was to determine the accuracy to which the received signal levels could be controlled. At the time of this test, the D/A converters used as an interface between the computer and the PIN-diode attenuators were 6-bit converters, which resulted

in a least-significant-bit resolution about 0.5 dB. When the tests were completed, it was found that the received signal strength could be controlled to ±0.5 dB, and, therefore, the limiting factor was the resolution of the D/A converters.

For the next tests, in Quito, Ecuador, and Santiago, Chile, in January and February 1971, the converters were increased in size to eight bits, with a resolution of about 0.12 dB. However, only a slight increase in the accuracy of the received signal level control was noted (≈0.4 dB). Figure 24 shows the AGC output plotted on a Sanborn recorder while the signal level controller program was in operation. Section A-B of the curve shows the AGC calibration, section B-C shows the AGC at 25 mm/s, and section D-E shows the AGC variation without the signal level controller program in operation.

A test of the entire system (Figure 25) was performed during June 1971 in London, England. The results of these tests were encouraging and are used as examples throughout this document. The only other result not shown in Figure 24 is an AGC curve obtained during the running of the real-time portion of TASP. This is presented in Figure 26.

7. CONCLUSIONS

The results of the L-band system testing have successfully demonstrated the capability of near-real-time processing of telemetry test data, the control of the ground-received signal to within ±0.5 dB, and the computer generation of test signals. This effort has established the framework for follow-on network testing programs such as near-real-time processing of Minitrack calibration data, collection and processing of PACT calibration data for control of the airplane, and acceptance testing of new antenna and receive systems.

The signal level controller is immediately applicable to aircraft tests currently being conducted (for example, antenna gain and pattern measurements). Also, the intent in developing TASP was to determine and exercise the maximum capabilities of the aircraft data generation and processing facility, thereby permitting more effective and efficient planning, development, and execution of network spacecraft simulations. Since the completion of this document, this effort has been reassigned and will continue under the Network Simulations Branch (Code 862), Unmanned Mission Simulations Section (Code 862.2). Also, the authors have been reassigned as follows: Mr. C. A. Scaffidi, Code 511.1; Mr. F. J. Stocklin, Code 863.1; Mr. M. B. Feldman, Code 862.2.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to all personnel who actively participated in this program, especially to Messrs. H. J. Mann and P. B. Farwell of GSFC and Messrs. P. Kawafuchi and C. Pickett of RCA for their noteworthy contributions during the field testing. Also, special thanks are expressed to Mr. P. Ondrus of GSFC for helping to prepare this document and to Mr. W. Jennings of GSFC for his efforts in packaging the L-band equipment.

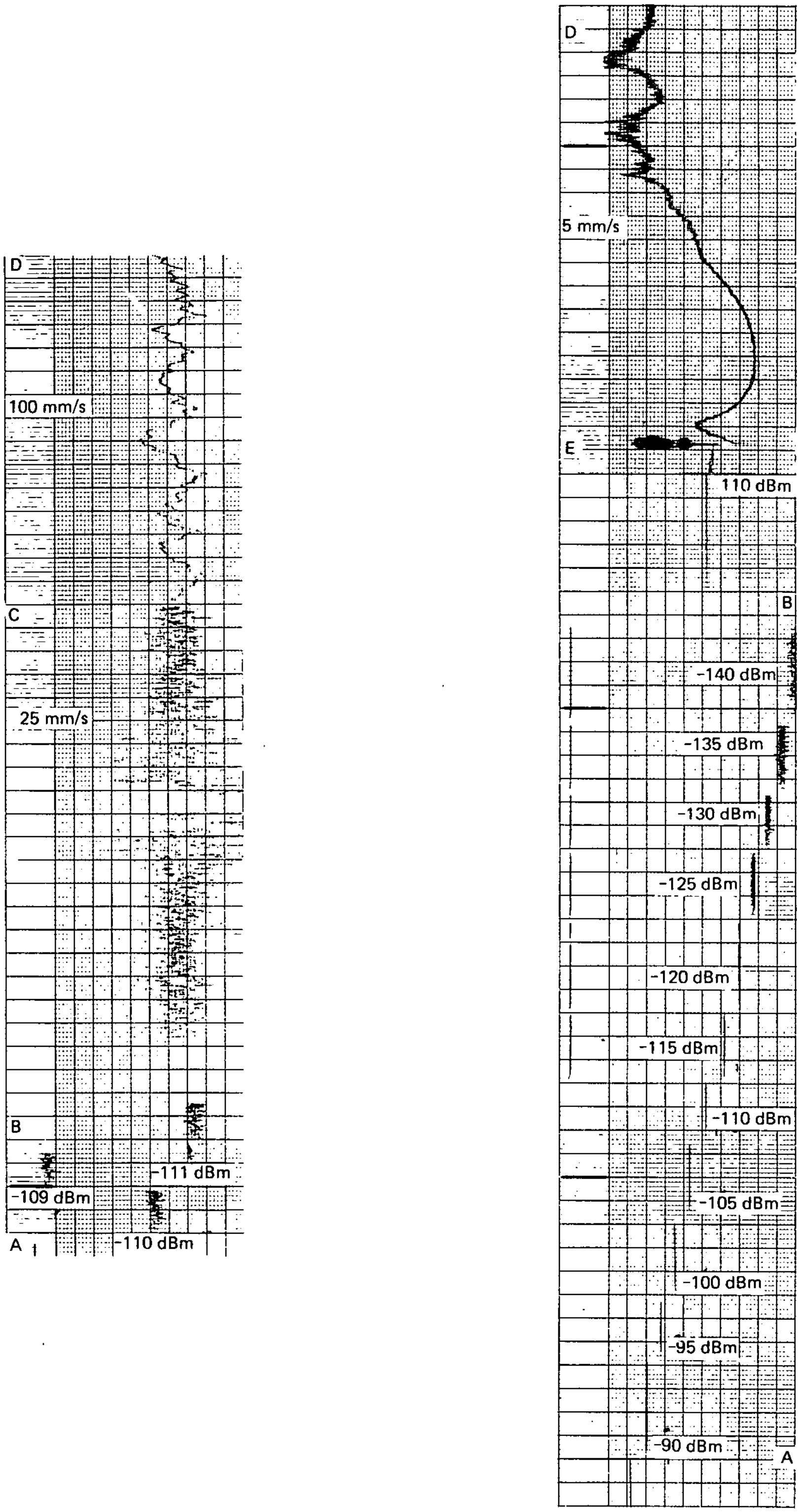


Figure 24—AGC of signal level controller program.

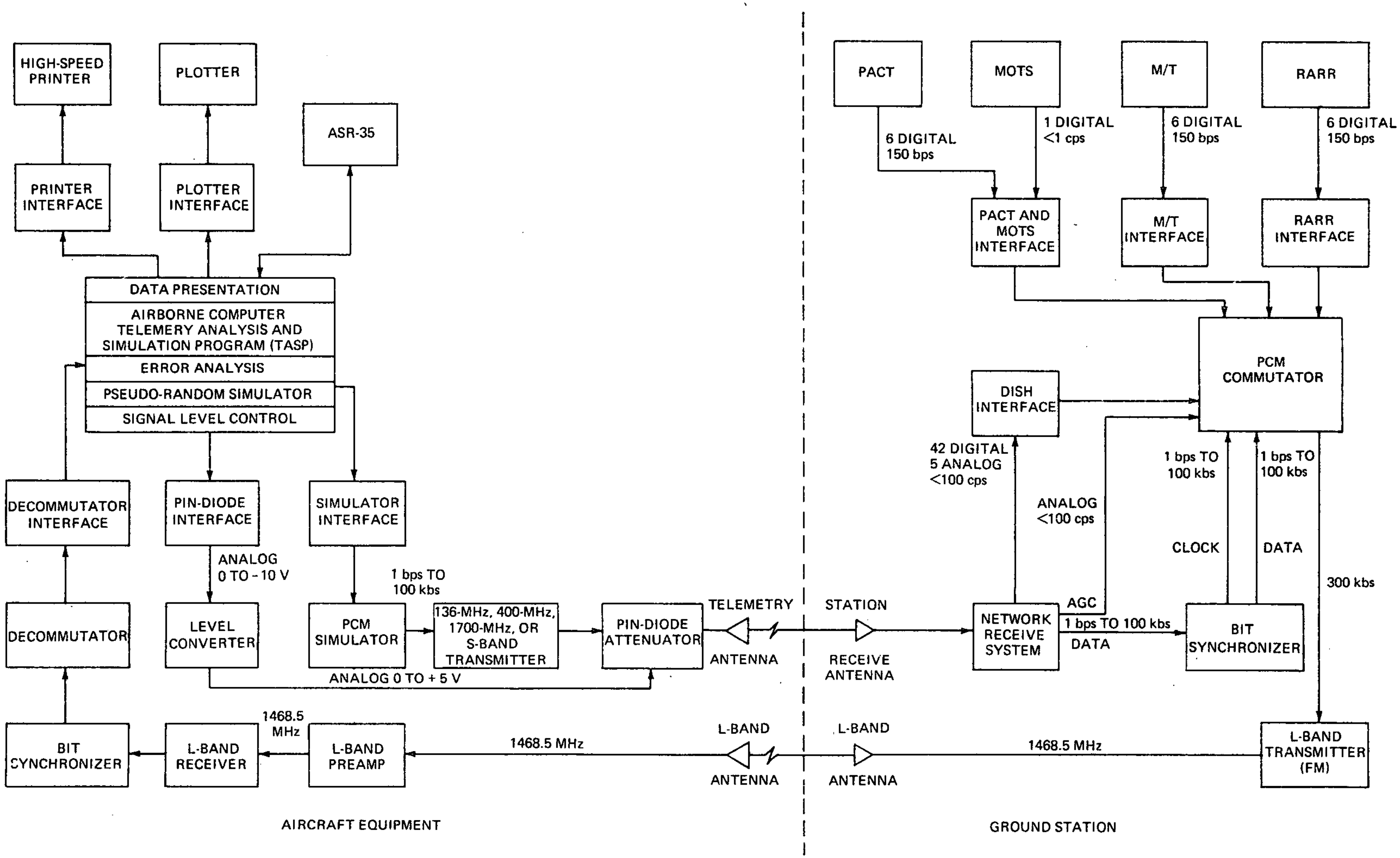


Figure 25—L-band telemetry system test configuration.

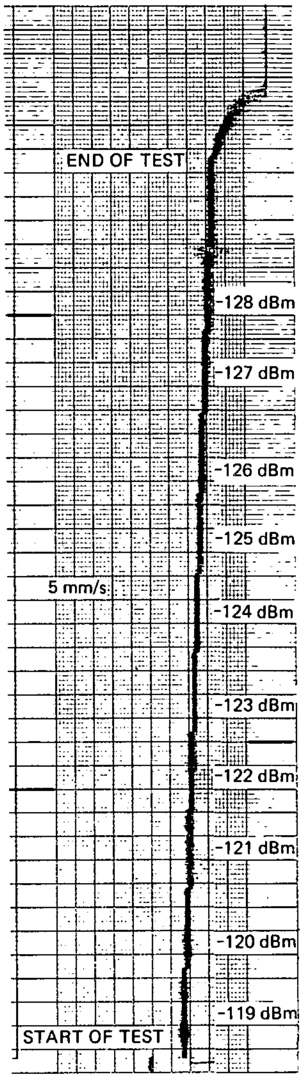


Figure 26–AGC curve from actual test.

Appendix A

WORST-CASE UPLINK LINK ANALYSIS FOR THE L-BAND TELEMETER

The following are the assumptions and calculations relating to the worst-case uplink link analysis for the L-band telemeter. If it is assumed that the maximum slant range for NASA-428 operations is 10 n.mi. at an elevation angle of approximately 30 deg off the horizon, the received signal strength and output S/N ratio at the airborne receiver is given as follows:

Carrier frequency	1468.5 MHz
Transmitter power	40 dBm
Space loss (at 10 n.mi.)	120 dB
Airborne antenna gain (at 30 deg)	2.5 dB
Ground antenna gain (at 30 deg)	2.5 dB

Figure A1 shows the basic aircraft configuration, together with the parameter values.

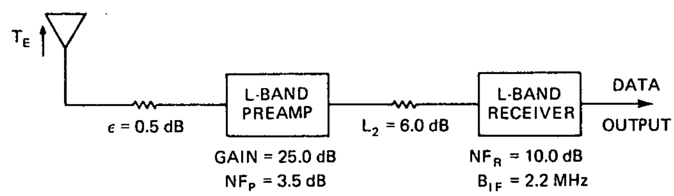


Figure A1—Aircraft receiver configuration.

The system temperature referenced at the preamplifier terminals is given by

$$T_S = \epsilon T_E + (1 - \epsilon)T_0 + (NF_P - 1)T_0 + \left(\frac{L_2 - 1}{G_P}\right) T_0 + \left(\frac{NF_R - 1}{G_P G_{L2}}\right) T_0 \ ,$$

where

ϵ = line loss from antenna to preamp input,

T_E = average earth temperature as viewed by airborne antenna ($\approx$275 K),

T_0 = ambient temperature of cable and preamp (290 K),

NF_P = preamp noise figure in dB,

L_2 = line loss from preamp to receiver,

G_P = preamp gain in dB,

NF_R = receiver noise figure in dB,

and

$G_{L2} = 1/L_2$.

If the airborne antenna is assumed to be looking at the ground, with an average temperature at 275 K,

$$T_S = 0.89(275) + 0.11(290) + 1.25(290) + \frac{3(290)}{325} + \frac{9(290)}{325(0.25)} = 675 \text{ K}.$$

Therefore, the noise spectral density is

$$\begin{aligned} \phi_S &= kT_s \\ &= -198.6 + 10 \log T_S \\ &= -170.3 \text{ dBm/Hz}. \end{aligned}$$

The noise power in the 2.2-MHz IF bandwidth is then

$$\begin{aligned} \text{Noise power} &= -170.3 + 10 \log (2.2 \text{ MHz}) \\ &= -107 \text{ dBm}. \end{aligned}$$

The signal power at the preamp input is the sum of the following:

Transmitter power	40.0 dBm
Transmitter cable loss	-0.5 dB
Space loss	-120.0 dB
Receiver cable loss	-0.5 dB
Receive antenna gain	2.5 dB
Transmit antenna gain	2.5 dB

Thus, the received signal strength is -76.0 dBm.

The C/N ratio in the IF predetection bandwidth is then +31.0 dB. With a modulation index of 1 as a minimum and a post-detection video noise bandwidth of 1 MHz, the threshold C/N ratio at the discriminator input (2.2-MHz IF) is given by*

$$(C/N)_{TH,IN} = 5 + 5 \log_{10} \frac{B_{IF}}{B_{PD}}$$
$$= 6.7 \text{ dB},$$

where

B_{IF} = IF predetection noise bandwidth

and

B_{PD} = post-detection video noise bandwidth.

The predetection C/N margin above the threshold point then becomes 31 − 6.7 = 24.3 dB. From Figure A2,* the output S/N value due to FM quieting is +35 dB for an input C/N ratio of +31 dB. In summary, a predetection margin of 24.3 dB for worst-case conditions should be sufficient to ensure essentially error-free data.

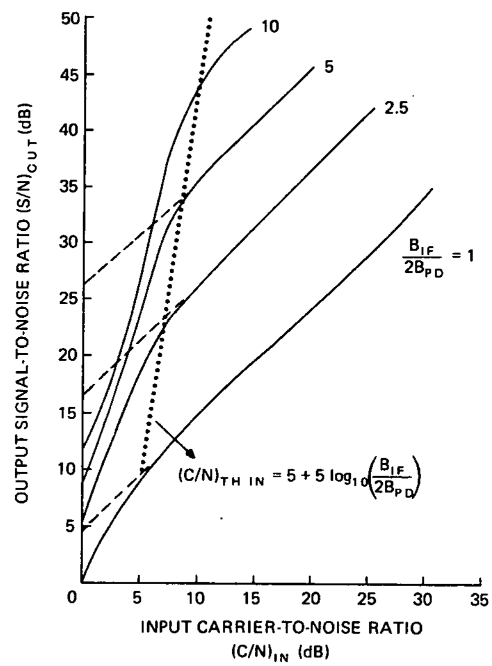


Figure A2—Threshold characteristics.

*J. J. Downing, "Modulation Systems and Noise", Prentice-Hall, New York, 1964.

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Appendix B

TABLE OF MODULATION INDEX VS. SIDEBAND AMPLITUDE FOR SQUARE-WAVE FREQUENCY MODULATION*

BETA (RAD)	C0 (DB)	C1 (DB)	C0/C1 (DB)	C2 (DB)	C3 (DB)	C4 (DB)	C5 (DB)
0.10	−0.04	−23.94	23.91	−52.06	−43.11	−64.11	−51.99
0.20	−0.14	−17.98	17.84	−40.06	−37.38	−52.16	−46.28
0.30	−0.32	−14.56	14.24	−33.08	−34.38	−45.27	−43.31
0.40	−0.58	−12.21	11.63	−28.18	−32.65	−40.49	−41.63
0.50	−0.91	−10.45	9.54	−24.43	−31.79	−36.90	−40.82
0.60	−1.33	−9.10	7.77	−21.42	−31.71	−34.08	−40.81
0.70	−1.83	−8.03	6.20	−18.93	−32.48	−31.84	−41.67
0.80	−2.42	−7.19	4.77	−16.82	−34.51	−30.02	−43.79
0.90	−3.11	−6.53	3.41	−15.02	−39.22	−28.58	−48.62
1.00	−3.92	−6.02	2.10	−13.46		−27.44	
1.10	−4.86	−5.65	0.79	−12.11	−37.04	−26.60	−46.74
1.20	−5.94	−5.41	−0.53	−10.94	−30.11	−26.04	−39.98
1.30	−7.20	−5.28	−1.92	−9.92	−25.78	−25.76	−35.85
1.40	−8.69	−5.26	−3.42	−9.03	−22.57	−25.79	−32.87
1.50	−10.45	−5.35	−5.11	−8.27	−20.00	−26.18	−30.55
1.60	−12.62	−5.54	−7.08	−7.62	−17.86	−27.02	−28.70
1.70	−15.39	−5.85	−9.55	−7.08	−16.04	−28.52	−27.21
1.80	−19.23	−6.26	−12.97	−6.63	−14.46	−31.13	−26.01
1.90	−25.61	−6.79	−18.82	−6.28	−13.09	−36.32	−25.06
2.00		−7.44		−6.02	−11.88		−24.35
2.10	−26.48	−8.24	−18.24	−5.85	−10.82	−34.87	−23.86
2.20	−20.97	−9.20	−11.77	−5.76	−9.89	−28.23	−23.60
2.30	−18.02	−10.34	−7.68	−5.76	−9.08	−24.14	−23.58
2.40	−16.14	−11.71	−4.43	−5.84	−8.37	−21.14	−23.84

*This table will be explained in detail in an X-Document by Frank J. Stocklin, "Relative Sideband Amplitudes vs. Modulation Index for Square-Wave/Sine-Wave Frequency Modulation and Phase Modulation", soon to be published.

61	2.50	−14.89	−13.38	−1.51	−6.02	−7.76	−18.75	−24.43
63	2.60	−14.06	−15.45	1.38	−6.28	−7.24	−16.78	−25.46
65	2.70	−13.55	−18.13	4.58	−6.64	−6.81	−15.10	−27.12
67	2.80	−13.30	−21.88	8.58	−7.10	−6.47	−13.65	−29.87
69	2.90	−13.28	−28.18	14.91	−7.67	−6.20	−12.39	−35.18
71	3.00	−13.46			−8.36	−6.02	−11.28	
73	3.10	−13.86	−28.91	15.05	−9.18	−5.92	−10.31	−33.95
75	3.20	−14.46	−23.33	8.87	−10.16	−5.89	−9.46	−27.40
77	3.30	−15.30	−20.32	5.02	−11.32	−5.94	−8.72	−23.40
79	3.40	−16.39	−18.38	1.99	−12.70	−6.07	−8.08	−20.48
81	3.50	−17.81	−17.07	−0.74	−14.38	−6.29	−7.53	−18.16
83	3.60	−19.66	−16.19	−3.47	−16.46	−6.59	−7.07	−16.25
85	3.70	−22.15	−15.63	−6.52	−19.14	−6.98	−6.69	−14.63
87	3.80	−25.72	−15.33	−10.39	−22.90	−7.47	−6.39	−13.24
89	3.90	−31.86	−15.26	−16.60	−29.21	−8.07	−6.17	−12.02
91	4.00		−15.40			−8.78	−6.02	−10.97
93	4.10	−32.29	−15.75	−16.54	−29.93	−9.63	−5.95	−10.04
95	4.20	−26.59	−16.32	−10.27	−24.35	−10.62	−5.95	−9.23
97	4.30	−23.45	−17.11	−6.34	−21.33	−11.80	−6.04	−8.53
99	4.40	−21.41	−18.17	−3.24	−19.40	−13.20	−6.20	−7.92
101	4.50	−20.00	−19.56	−0.44	−18.09	−14.89	−6.44	−7.40
103	4.60	−19.02	−21.37	2.35	−17.20	−16.98	−6.76	−6.97
105	4.70	−18.37	−23.82	5.45	−16.63	−19.68	−7.18	−6.62
107	4.80	−17.98	−27.36	9.38	−16.33	−23.45	−7.68	−6.34
109	4.90	−17.83	−33.47	15.64	−16.25	−29.76	−8.30	−6.14
111	5.00	−17.90			−16.39		−9.03	−6.02
113	5.10	−18.18	−33.85	15.67	−16.73	−30.50	−9.89	−5.97
115	5.20	−18.68	−28.12	9.44	−17.29	−24.93	−10.90	−6.00
117	5.30	−19.41	−24.95	5.54	−18.08	−21.91	−12.09	−6.10
119	5.40	−20.41	−22.88	2.47	−19.13	−19.98	−13.50	−6.27
121	5.50	−21.74	−21.45	−0.29	−20.51	−18.67	−15.20	−6.53
123	5.60	−23.50	−20.45	−3.06	−22.32	−17.79	−17.30	−6.87
125	5.70	−25.90	−19.77	−6.13	−24.76	−17.22	−20.01	−7.30
127	5.80	−29.39	−19.36	−10.03	−28.29	−16.92	−23.78	−7.82
129	5.90	−35.45	−19.19	−16.26	−34.39	−16.85	−30.11	−8.45
131	6.00		−19.24			−16.99		−9.19
133	6.10	−35.74	−19.50	−16.24	−34.75	−17.33	−30.86	−10.06
135	6.20	−29.97	−19.98	−9.99	−29.02	−17.89	−25.30	−11.08
137	6.30	−26.77	−20.69	−6.08	−25.85	−18.68	−22.29	−12.28
139	6.40	−24.66	−21.67	−2.99	−23.77	−19.73	−20.36	−13.70

141	6.50	−23.19	−22.98	−0.21	−22.33	−21.11	−19.06	−15.41
143	6.60	−22.15	−24.73	2.57	−21.32	−22.92	−18.18	−17.52
145	6.70	−21.45	−27.11	5.66	−20.64	−25.36	−17.62	−20.23
147	6.80	−21.01	−30.58	9.57	−20.22	−28.89	−17.32	−24.02
149	6.90	−20.81	−36.63	15.82	−20.04	−34.99	−17.25	−30.34
151	7.00	−20.82			−20.08		−17.39	
153	7.10	−21.06	−36.89	15.83	−20.34	−35.35	−17.74	−31.11
155	7.20	−21.50	−31.10	9.60	−20.81	−29.61	−18.30	−25.55
157	7.30	−22.19	−27.88	5.69	−21.51	−26.44	−19.09	−22.55
159	7.40	−23.15	−25.76	2.61	−22.49	−24.36	−20.15	−20.63
161	7.50	−24.43	−24.28	−0.16	−23.79	−22.92	−21.53	−19.33
163	7.60	−26.15	−23.23	−2.93	−25.53	−21.91	−23.34	−18.45
165	7.70	−28.51	−22.51	−6.00	−27.90	−21.22	−25.78	−17.90
167	7.80	−31.96	−22.06	−9.91	−31.37	−20.81	−29.31	−17.60
169	7.90	−37.99	−21.84	−16.15	−37.41	−20.63	−35.42	−17.54
171	8.00		−21.85			−20.67		−17.68
173	8.10	−38.21	−22.07	−16.14	−37.66	−20.92	−35.78	−18.03
175	8.20	−32.40	−22.50	−9.89	−31.87	−21.39	−30.04	−18.60
177	8.30	−29.16	−23.18	−5.98	−28.64	−22.09	−26.87	−19.39
179	8.40	−27.02	−24.12	−2.90	−26.52	−23.06	−24.79	−20.45
181	8.50	−25.52	−25.40	−0.12	−25.03	−24.37	−23.35	−21.83
183	8.60	−24.45	−27.11	2.66	−23.97	−26.10	−22.34	−23.64
185	8.70	−23.72	−29.46	5.74	−23.24	−28.47	−21.65	−26.09
187	8.80	−23.25	−32.90	9.65	−22.79	−31.94	−21.24	−29.63
189	8.90	−23.02	−38.91	15.90	−22.57	−37.98	−21.06	−35.73
191	9.00	−23.01			−22.57		−21.10	
193	9.10	−23.21	−39.11	15.90	−22.78	−38.22	−21.35	−36.10
195	9.20	−23.63	−33.30	9.66	−23.21	−32.42	−21.81	−30.36
197	9.30	−24.29	−30.05	5.76	−23.88	−29.20	−22.52	−27.19
199	9.40	−25.23	−27.90	2.68	−24.82	−27.07	−23.49	−25.11
201	9.50	−26.49	−26.39	−0.10	−26.09	−25.57	−24.79	−23.67
203	9.60	−28.18	−25.31	−2.87	−27.80	−24.52	−26.53	−22.66
205	9.70	−30.52	−24.57	−5.95	−30.14	−23.79	−28.90	−21.98
207	9.80	−33.95	−24.09	−9.86	−33.58	−23.33	−32.36	−21.56
209	9.90	−39.95	−23.85	−16.09	−39.59	−23.11	−38.40	−21.38
211	10.00		−23.84			−23.10		−21.42

Appendix C

L-BAND TELEMETRY SYSTEM ENVIRONMENTAL REQUIREMENTS

EQUIPMENT NOT OPERATING

The equipment, when not operating, shall not be damaged when stored, shipped, or otherwise subjected to the following environment:

(a) Temperature: −65°F to +160°F.

(b) Relative humidity: 0 to 100 percent.

(c) Altitude: sea level to 35 000 feet.

(d) Shock and vibration such as that encountered in transportation and handling by common carriers at sea, in the air, and over extremely rough terrain.

(e) Salt atmosphere such as that encountered near the ocean, for equipment to be operated on land without shelter or on ships.

(f) Dust storms such as those encountered on desert terrain, for equipment to be operated without shelter.

EQUIPMENT OPERATING

The equipment shall be designed to be operated according to the individual equipment specifications and within the following environment:

(a) Temperature: −30°F to +130°F for equipment operating without shelter; 40°F to 100°F for equipment operating within shelter.

(b) Relative humidity: 0 to 100 percent for equipment operating without shelter; 0 to 80 percent for equipment operating within shelter.

(c) Altitude: sea level to 15 000 feet.

(d) Shock and vibration such as that induced by the operation of nearby electromechanical equipment (power generating devices) for ground installations, or such as that induced by the ship or aircraft operation for ship or aircraft installations.

(e) Salt atmospheres such as those encountered near the ocean, for equipment to be operated on land without shelter or on ships.

(f) Dusty atmospheres such as those encountered during desert storms, for equipment to be operated without shelter.

(g) Electromagnetic interference such as that encountered at any of NASA's stations within the network. The equipment shall not, in itself, be a source of interference which might adversely affect the operation of other equipment. Interference control shall be considered in the basic design of all electronic and electrical systems, subsystems, and components. The design shall be such that interference generated and propagated by the equipment shall be minimized before the application of interference control devices. The application of these devices, such as filtering, shielding, and bonding, shall conform to good engineering practice.